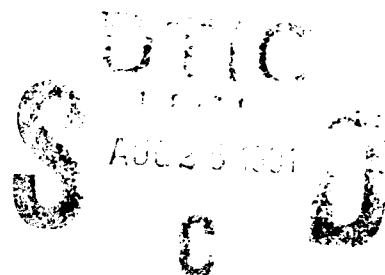


**Compilation of 1990 Annual Reports  
of the Navy ELF Communications System  
Ecological Monitoring Program**

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Volume 2 of 3 Volumes:  
Tabs C-F

**AD-A239 869**



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August 1991

Prepared for:

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Submitted by:

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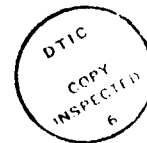
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## FOREWORD

During 1990, the Navy continued to conduct long-term studies monitoring for possible effects to biota from operation of their ELF Communications System. The Space and Naval Warfare Systems Command (SPAWAR) funded these studies through a contract to IIT Research Institute (IITRI). IITRI provided engineering support and overall program management of monitoring studies performed by university subcontractors.

The reports compiled (Tabs A-H) in this three-volume document present the progress and findings of ongoing studies located near the Naval Radio Transmitting Facility--Republic, Michigan. At least four scientific peers reviewed each report. Study investigators considered the peer critiques prior to providing a final copy of their annual report to IITRI. These annual reports are compiled here without further change or editing by SPAWAR or IITRI. As is done for all program documents, IITRI has submitted this compilation to the National Technical Information Service for unlimited distribution. Past compilations and other program documents are listed under Tab I.

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| A-1          |  |





**ELF COMMUNICATIONS SYSTEM  
ECOLOGICAL MONITORING PROGRAM**

**INDEX OF 1990 ANNUAL REPORTS**

- A.     Herbaceous Plant Cover and Trees:  
       Becker, K. T.; Bruhn, J. N.; Cattelino, P. J.; Desanker, P.; Fox, K. B.; Gale, M. R.; Jurgensen, M. F.;  
       Liechty, H. O.; Mroz, G. D.; Ouyang, H.; Reed, D. D.; Reed, E. J.; Richter, D. L.; Wu, Y.; Zhang,  
       Y. F.
- B.     Litter Decomposition and Microflora:  
       Bruhn, J. N.; Bagley, S. T.; Pickens, J. B.
- C.     Soil Amoeba:  
       Band, R. N.
- D.     Arthropoda and Earthworms:  
       Snider, R. J.; Snider, R. M.
- E.     Pollinating Insects: Megachilid Bees:  
       Strickler, K.; Scriber, J. M.
- F.     Small Mammals and Nesting Birds:  
       Beaver, D. L.; Hill, R. W.; Hill, S. D.
- G.     Bird Species and Communities:  
       Blake, J. G.; Hanowski, J. M.; Niemi, G. J.; Collins, P. T.
- H.     Aquatic Ecosystems:  
       Burton, T. M.; Stout, R. J.; Taylor, W. W.; Winterstein, S.; Mullen, D.; Marod, S.; Eggert, S.;  
       Repert, D.; Radhakrishna, J.
- I.     Listing of Technical Reports.

1. Cover page:

a. Subcontractors name and address:

Rudolph Neal Band  
Department of Zoology  
Michigan State University  
East Lansing, MI 48824

b. Subcontract number: E06595-88-C-003

c. Title: ELF Communications System Ecological Monitoring  
Program, Task 5.2, Soil Amoeba.

d. Reporting year: November 1, 1989 to October 31, 1990.

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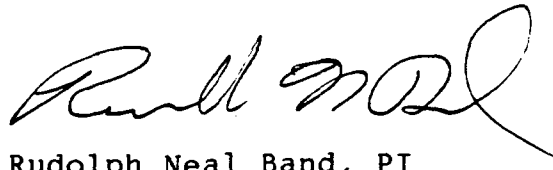
Rudolph Neal Band  
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Richard L. Howe, Assistant Director

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3. Table of Contents:

|   |     |
|---|-----|
| 1. Cover page . . . . .                     | i   |
| 2. Frontispage . . . . .                    | iii |
| 3. Table of Contents. . . . .               | v   |
| 4. Abstract . . . . .                       | vi  |
| 5. Summary . . . . .                        | vii |
| 6. Progress Report . . . . .                | 1   |
| a. Objectives . . . . .                     | 1   |
| b. Work Plan . . . . .                      | 1   |
| c. Experimental . . . . .                   | 9   |
| 7. Peer Reviewers and Publications. . . . . | 15  |
| 8. Literature Cited . . . . .               | 16  |
| 9. Tables and Figures . . . . .             | 17  |

#### 4. Abstract:

The four years prior to 1990 were drought years. The NOAA weather data 1990 also indicates that this was a dry year. For the fifth growing season again growth was suppressed although not as marked as in the past 4 years. This is in contrast with the 1984 and 85 growing seasons, in which abundant rainfall took place and the population increase in soil amoebae during the growing season was far greater.

During the 1990 growing season the ELF antenna was operated more frequently than in prior years. This provides 2 years of intermittent ELF exposure (i.e. 1989 and 1990) for the biological systems to react to the radiation, one year of very limited exposure and greater exposure in 1990. Assuming a full ELF exposure in 1991, this means that the present study will be based on 2 years of ELF exposure or less if the antenna operation in 1990 was intermittent. I do not think that this is enough exposure time to make an adequate judgement about ELF effects on soil ecology. Although direct effects of ELF radiation may be obvious after a short exposure time, ecological consequences include indirect components which take time to develop. This was the basis for the National Academy's recommendation for ecological studies of ELF radiation. Additional data-collecting years would make this a more effective study.

The antenna, ground and control sites used in previous years were continued. The sites have been characterized by IITRI personnel so that all sites have a similar 60 cycle electromagnetic background while the control site is essentially devoid of ELF radiation from the antenna.

I have been monitoring various physical and chemical properties of the sites as well as their biological characteristics.

At all sites, population size fluctuations were observed, as was the case in previous years. Of course the fluctuations were not as dramatic for the drought seasons, as they were in 1984 and 1985. Growth rates of amoebae in soil submerged cultures, developed over previous seasons, were performed in 1990. Isozyme analyses of amoebae grown in submerged cultures failed to reveal effects of ELF radiation at the gene level. A method for counting bacteria was developed and applied to one site; this will be used in the 1991 season at all sites in parallel with amoeba counts.

#### 5. Summary:

Plot selection and characterization: soil chemistry was performed on all sites in 1990, as was done in previous years. As in past years, differences in soil chemistry were noted between sites although these were within the same order of magnitude.

Species and strain characterization: In 1986, 1987 and 1988, Acanthamoeba polyphaga was used to test for strain heterogeneity within and between the sites. Isoenzyme analysis was used to detect strain differences. No differences were found between sites. Budget constraints forced the elimination of this aspect of the study for the present. If the 1991 season has adequate rain to support active growth of amoebae in soil, then it will be worth the effort to do an isoenzyme analysis to see if genetic diversity has changed and whether this is affected by ELF radiation. As noted below, isozyme analyses were used to detect

possible changes in amoebae grown in the presence of the electric currents generated by the ELF antenna.

Population size: the fluctuation in population of amoebae during the growing season was determined as in past years. No differences were noted in total population size between study sites for a given horizon and sampling date except for the September count of the upper, organic soil horizon in which the control site population was slightly larger than the other sites. As in past years differences were noted in the number of dormant cysts between sites. Again for 1990, a dry year, population sizes did not reach those observed in normal rainfall years (e.g. 1984, 1985).

Growth and feeding activity: to test growth rate of amoebae, soil submersible culture vessels were designed. Although the antenna was not fully operational in the 1990 growing season, it was used for sufficient time to do growth and isozyme experiments. No differences in growth rate or isoenzyme heterogeneity was observed between sites.

Ambient monitoring: soil temperature and moisture were monitored continuously during the field season, as was done in previous years. The moisture content of soil in the Spring of 1986, 1987, 1988, 1989 and 1990 was lower than normal rainfall years. This and total rainfall correlated to small populations of amoebae in the soil during these years. Soil temperature over the growing season was the same between study sites. Temperature changes from Spring to Fall for 1990 ranged from approximately 10 to 17° C over the growing season.

## 6. Progress report:

OBJECTIVES: The project objective is to determine possible effects of ELF radiation on amoebae in soil. The sites chosen for this study are adjacent to the Michigan ELF transmitter facility and include control, antenna and ground wire study sites.

For the 1990 field season the ELF antenna was operating more frequently than in 1989. I do not have access to antenna operation data yet, but this may represent a normal operational year in which case 1990 would be the first year of full exposure to ELF radiation.

### WORK PLAN ELEMENTS:

#### #0. Plot selection and characterization.

Synopsis: Statistical analysis of soil chemistry shows some variability between sites, as was the case for data from 1986, 1987, 1988 and 1989. This may be due to the prolonged drought that has continued from 1986. Prior to the drought (e.g 1985) differences were not observed between sites. Likewise this could be due to differences in the variability of data between years.

#### #1. Species and strain characterization.

Synopsis: using morphological and physiological markers, identify species and strains of soil amoebae from the study areas so that



possible changes in the population due to ELF can be detected. For budgetary reasons this portion of the work plan was deleted for the 1990 season. The allozyme methods developed for genetic analyses and a clonal isolate of A. polyphaga from previous years was used in Work Plan #3.

## #2. Population size and activity.

Synopsis: determine population size of amoebae in soil and the ratio of vegetative to dormant amoebae over the growing season. This is a productivity measure which could be affected by ELF radiation. It could also be a reflection of changes in the microbial food organisms due to ELF radiation. Direct ELF effects on amoeba growth vs. indirect effects on food organisms can be distinguished in two ways: growth of amoebae in culture vessels exposed to ELF radiation (see #3 below) and isozyme analyses. Direct counts of bacteria in soil were attempted at one site for two sampling dates.

Specifics: an established soil dilution counting procedure is used (Singh, 1946 as modified by Darbyshire et al., 1974). In order to count vegetative amoebae and cysts, samples are first divided in half, one-half is used to count total cysts and vegetative amoebae while the other half is treated to kill amoebae so that only cysts are counted. Differential counts are used to calculate by subtraction the total vegetative amoeba count. In the 1983 season I found that 8 random samples,

subdivided into organic and mineral horizons (ie. 8 samples per horizon), provided statistically significant data;

I will repeat this from the 1983 report: ten samples were counted from each horizon at the three sites on two dates; the results indicated a coefficient of variation that was less than 10% of the mean for a given horizon and date. From a 90% power curve, significant differences could be detected at 1.4 X std. dev. for a sample size of 10 and 1.5 to 1.6 X std. dev. for a sample size of 8. Thus sample sizes of 8 and 10 were almost equally powerful so that 8 random samples were taken from each horizon at the three sample sites on a sampling date.

One-way analysis of variance was used to detect differences in total amoeba and cyst count between control, antenna and ground sites for each horizon in 1989. I was advised by Professor John Gill at MSU, a statistician who works with biological problems, that log transformed data should be used for statistical analyses. Since the microbial population doubles over time, log transformed data more closely reflects biological events. Table 4B gives the error (i.e. among) degrees of freedom as 21. Direct counts of amoebae in soil, as is done with freshwater organisms (e.g. Wright & Coffin, 1984) is not possible. Microbes adhere to soil and sonication of a soil slurry to release them might make quantitative recovery of some organisms by subsequent density flotation possible, but amoebae would be destroyed.

Bacterial population sizes were be estimated (Hanssen et al. 1974; Hobbie et al., 1977) to see if there is a correlation to fluctuations in protozoan populations. This technique was suggested by David Harris in Dr. Paul Elder's lab at Michigan State University, Dept. of Crop and Soil Science.

### #3. Growth and feeding activity.

Synopsis: determine the in situ growth and feeding activity of amoebae in soil submersible culture vessels. This will provide data on growth rate, feeding activity and mean generation time (i.e. the cell cycle between nuclear mitoses).

Rationale: the approach utilizes a known amoeba species previously isolated from the study site, Acanthamoeba polyphaga and characterized as part of the isoenzyme study. Direct counts of amoebae are made with a microscope to determine increase in number of organisms and nuclei over time. A log transform of these data provides a straight line plot which can be quantified by regression analysis. Statistically significant differences between slopes can be detected with confidence limits of the line, a version of the t-test. This approach will be used to determine growth rate and thus mean generation time. Mean generation time is comparable to the cell cycle measurement of time between mitoses of Physarum. Isozyme analyses are done before and after serial growth in the culture vessels subjected to ELF-induced electromagnetic effects, to detect possible genetic changes in the exposed amoebae. This involved 13 different isoenzymes and between 25 and 30 gene loci. We had previously developed this technique (e.g. Jacobson & Band, 1987) for screening clonal isolates of A. polyphaga from soil to look for genetic effects, using Nei's (Nei, 1972) statistical methods for comparing data between sites. In 1987 we conducted an extensive study of genetic diversity in populations of Acanthamoeba polyphaga at the study sites. This will be repeated

in 1991. Biological diversity is studied at various levels (e.g. Gibbons, 1987) including ecosystem diversity, species diversity and genetic diversity. I chose to study genetic diversity since it is a sensitive indicator of effects within the species. Diversity at the level of species composition was not chosen since it depends on species identification. The species concept in theory is difficult to apply to microorganisms with different methods of genetic recombination or none (i.e asexual reproduction). In practice, purely morphological studies are impractical, especially with the small amoebae (or flagellates). Lastly, the enrichment methods may not reveal the full spectrum of protozoa that exist in the soil.

Culture chambers, containing electrodes to use in conjunction with ELF induced soil currents, were designed with the help of IITRI personnel. To measure growth rate of amoebae directly in soil would be ideal, but the techniques to do this are inefficient, labor intensive and not as accurate as direct counts of amoebae (i.e. soil dilution counts similar to those used to measure the number of amoebae present in soil). Further, uncontrolled interactions with other soil organisms could affect amoeba growth. Soil water is a saline suitable for amoeba growth, but it does not exist as a continuous aqueous phase in soil. Therefore soil exhibits a higher electrical resistance than would be the case for soil water alone over a comparable distance, which is also the case for culture vessels, in which the saline is a continuous phase between the electrodes. Therefore two different culture vessel configurations are used,

one to mimic the voltage induced in soil by the ELF radiation (with a greater current, since the resistance in saline is less than a comparable distance in soil) and the other to mimic soil current (with a smaller voltage than observed in soil). In previous seasons, it was established that chambers buried at research sites yielded growth rates that were not statistically different. Since 1985, IITRI personnel have cooperated in the design and construction of electrical components used in the soil growth experiments. The recent design includes continuous recording of soil voltages throughout the season as well as providing the electrical connections to the soil submersible culture vessels.

#### #4. Ambient monitoring.

Synopsis: soil temperature and moisture are monitored. Both measures are useful for general trends but fail to correlate to changes in amoeba populations. The multi-year drought (i.e. 1986 to 1989 and possibly 1990) had a dramatic effect on soil amoeba population size although this was better reflected in annual precipitation patterns than in soil moisture. Soil temperature changes little over a growing season. In addition to monitoring ELF-induced soil voltages, IITRI personnel added temperature measurements as well, a useful added piece of environmental data.

#### #5. Data analysis.

Synopsis: statistical analyses mentioned earlier are summarized here. For amoeba counts in soil, by soil dilution procedures, a one-way analysis of variance with 8 replicates per cell was adequate (see Work Plan element #2 for details). One-way analysis of variance was used for soil counts (Table 4B) and soil moisture (Table 5) because it is not possible to compare accurately soil horizons or sampling dates. Soil horizons differ markedly in their densities. Bulk density of the organic and mineral horizons were presented in the 1983 annual report; the ratio of mineral to organic soil was 2.9. When this ratio is used to compare soil counts of the organic and mineral horizons some data fits this ratio but in most cases only a tendency can be observed. Thus soil counts corrected for bulk density differences between organic and mineral horizons will tend to be closer in count so that the bulk density data does indicate that mineral horizon population sizes are not too different from population sizes in the overlying organic horizon. Moisture and counts differ between sampling dates. Growth measurements in culture chambers were analyzed with regression lines, comparing slopes with confidence intervals (i.e. a t-test). Other statistical comparisons (e.g. soil chemistry, soil pH, etc.) are done by analysis of variance. For isoenzyme determinations, comparisons between isolates are done by the method of Nei (1972).

SCHEDULE OF WORK ELEMENTS (Nov. 1 to Oct. 31 each year)

| MONTH   |   |   |   |   |   |   |   |   |   |    |    |    |
|---------|---|---|---|---|---|---|---|---|---|----|----|----|
| Element | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 |
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| 2       |   |   |   |   |   | X | X | X | X | X  | X  |    |
| 3       | X | X | X | X | X | X | X | X | X | X  | X  |    |
| 4       |   |   |   |   |   | X | X | X | X | X  | X  |    |
| 5       | X | X | X | X | X |   |   |   |   |    |    |    |
| Reports | X | X | X | X | X | X | X | X | X | X  | X  | X  |

\* Omitted in the 1989 season.

## EXPERIMENTAL

Methods and results will be presented in reference to the Work Plan, given above.

#0. Plot selection and characterization. Site selection is now complete.

Table 1 shows the chemical properties of the organic and mineral horizons for the control, antenna and ground wire sites, with replicates. As in past seasons, differences exist between sites. This might be attributable to the drought which has extended over four years, 1986, 1987, 1988 and 1989. The chemical content of soil in 1989 was similar to 1988. As noted in the 1985 report, in view of the wide fluctuation in population size of amoebae seen throughout a given growing season, it would be of interest to see if this is reflected in soil ammonium levels. In consultation with Dr. J. Tiedje of the Department of Crop and Soil Sciences, it was determined that the rapid passage of ammonia through the ecosystem would make this impractical. Thus soil ammonium has not been determined. Table 2 demonstrates some significant differences between sites and sampling dates although values shown in Table 1 are consistent between horizons. Table 3 demonstrates the slightly acidic nature of the soil in a northern hardwood forest, with some differences between sites and horizons. Both horizons were comparable to 1989 pH determinations.

#1. Species and strain characterization. Species of soil amoebae present at the study sites were isolated from soil



enrichment plates. So far no species differences have been noted between sites; species composition was the same as in previous years. Species included Acanthamoeba castellanii, A. polyphaga, A. astronyxis (small strain), Hartmannella sp., Rosculus sp., Naegleria gruberi, Vahlkampfia sp., and Mayorella sp. The isoenzyme analysis of genetic heterogeneity of A. polyphaga was not done in 1990, but will be done in 1991.

#2. Population size and activity. As stated in previous annual reports, the number of replicate soil samples required to statistically compare soil amoeba populations between study sites was 8. From 1983 to 1985 soil amoeba populations increased from the start of the growing season to a peak in excess of a million amoebae/gram soil in August and then dropped sharply in September to a few thousand/gram soil. Vegetative amoebae formed a significant component of each monthly sample, including the smaller September and October populations. No differences were noted for a given soil horizon between the antenna, ground and control sites. The drought, beginning in 1986, has had a pronounced effect on population size, the ratio of vegetative to dormant cysts and some site differences in 1987 (the June and July counts. The results from the 1990 season obtained to date show population sizes characteristic of a dry year but better than the prior 4 years. Table 4 gives total counts of vegetative amoebae and cysts while Table 4A gives counts of cysts alone, thus the mathematical difference gives the number of vegetative amoebae present in a sample. Figure 1 interprets Tables 4 and 4A in showing total counts and the calculated percent vegetative

amoebae by horizon and site at various sampling dates. Figure 1H summarizes maximum average yields for all sites by year and month to illustrate the general trend in maximum population changes.

Table 4B demonstrates that the total population size in the organic horizon at the control site was greater (i.e. 5% level, Table 4B) than other sites for the September count; otherwise no significant differences were noted between sites for a given horizon and sampling date. As in past years cyst counts exhibited differences between sites which reflect the susceptibility of vegetative and cyst states to local conditions (e.g. food and moisture might explain these differences).

Bacterial counts were performed at the control site on two dates in August and September, 1990. The data (Table 8) indicates a three-fold difference in counts between the organic and mineral horizons, consistent with bulk density differences previously noted for amoeba counts. Both horizons contained more bacteria in September. Since the technique is promising, I intend to do bacterial counts monthly in parallel with amoeba counts in 1991. The number of bacteria appears rather large but not out of range for published estimates.

I have summarized the NOAA Climatological Data publications for monthly deviations from normal rainfall for 1985 through 1990 (Fig. 3) to illustrate the drought years. Soil moisture measurements indicate slightly drier soils during this period (Fig. 2), which may account for the effects of the drought on growth, although nutrient input from surface litter may be a more important component of limiting amoeba growth and would correlate

with the rainfall pattern. Soil suction is an important moisture variable for soil (e.g. Darbyshire, 1975). For example, clay has finer pores than sand so that at the same water content, the larger pores in sand would be filled with water and capable of supporting growth of large microorganisms, if the water content was sufficient to do this. At the same water content, the finer pores in clay would be too small to contain larger microorganisms. Again, gross moisture content of sand and clay would differ with the same sized pores filled with water. This can be seen in the data (e.g. Table 5), modified by drainage considerations, recent rain history and soil heterogeneity -- i.e. sand has a lower moisture content. Since the capillarity of soil can be measured allowing a calculation of pore sizes filled with water at a given moisture content, it is theoretically possible to specify the water content required in a given soil to support growth of a microorganism of a given size. This was done by Darbyshire (1975) for a large ciliate. In the 1983 annual report I measured water binding in study site soils (i.e. soil suction) to ascertain the range of moisture needed to support growth of soil amoebae. Soil moisture measurements during the growing season were less than the calculated figures; further, the fluctuation in population size over the growing season did not correlate to moisture content (Fig. 1 for all years). Either the soil suction methods I used were inaccurate or the amoebae were growing on wet surfaces as well as water-filled soil pores. In Figs. 3A and 3B the annual total rainfall is plotted together with the average maximum total amoeba population per year; this

gives a good correlation between population size and annual rainfall.

#3. Growth and feeding activity. Growth experiments in soil submersible culture vessels were done over prolonged intervals in the 1989 field season. Past years have demonstrated that the technique is suitable, although prolonged incubation did reveal that corrosion between the electrode and the soldered wire attached to it was still a significant problem. The metal ions from corrosion leached into the saline, dramatically altering conductivity. This was eventually solved with better polyurethane sealants and in 1990 IITRI personnel improved the seal further with an autoclavable silicone sealant. In 1990 we took glutaraldehyde-fixed samples back to the lab for counting. Amoebae were counted during active growth, which was a good deal cooler than the temperatures normally used for laboratory isolates (e.g. 23 to 30° C). Cultures were left in the soil after growth reached its maximum for another 2 weeks and then subcultured. In some cases the cultures became contaminated with a small flagellate; then subcultures were made from flagellate-free cultures. At the end of the season, isoenzyme analyses were done on these amoebae. No change in isoenzyme pattern was observed between the original clone culture and subcultures grown in soil incubated at the sites (Fig. 6). Growth rate data analysis is presented in Table 6 and indicated no difference between sites. For the 1990-growth experiments I decided to use an excess of bacterial food to support both maximum amoeba growth rate and maximum yield. Thus vegetative amoebae persisted longer

in the soil submersible culture vessels than they would with limiting numbers of bacteria. Analyses were done during exponential growth (Fig. 5) to simplify statistical comparisons and to avoid growth limits caused by a decrease in the bacterial food supply. The data in Fig. 5 is presented and analyzed in Table 6; the intent of Fig. 5 is to give a general idea of growth rates illustrated as regression lines. If bacteria decreased to the point where the growth of amoebae became limiting, this would have been seen in Fig. 5 as a deceleration in the growth rate. In 1988 growth at 12' in the laboratory (MGT = approx. 7.2 hr) was compared to growth at 17' C (MGT = approx. 3.6 hr) (in 1988) and the differences emphasize the need to track soil culture temperature closely. Temperatures have been the same between study sites, but this is still an important variable if this is not the case in future seasons. Again, comparisons of growth experiments done at different times of the year will certainly be affected by temperature which will differ over the season.

#4. Ambient monitoring. Table 5 (and Fig. 2) gives the mean % (w/w) moisture for individual measurements, taken when the soil was sampled. During the growing season (i.e. June, July and August) the soil was drier than in 1984 and 1985, roughly comparable to the drought years.

Soil temperature recordings for the season (Fig.4) were comparable to previous field seasons. Table 5 compares IITRI temperature data with my data to demonstrate a similarity in data. Since different soil depths were probably used, it is a useful coincidence to note this temperature similarity.

7. Peer reviewers and publications:

I plan to use the following individuals as peer reviewers:

- a. Prof. Thomas J. Byers  
Department of Molecular Genetics  
Ohio State University
- b. Prof. Frederick L. Schuster  
Department of Biology  
Brooklyn College

Publications (1990):

- 1. Hu, Wang Nan & Band, R. N. 1991. Pathogen related protein synthesis in Naegleria fowleri. Infect. & Immun. accepted for publication.
- 2. Band, R.N., Anzaldua, S.E., Pankratz, S.H. & Schuster, F.L. 1991. The proteosome, a new organelle found in Naegleria spp. J. Cell Sci. submitted for publication.
- 3. Presented at the 1991 Midwest Protozoology Meeting, Univ. of Illinois, Chicago: Isolation of Naegleria fowleri cDNA associated with pathogenicity.
- 4. In preparation: Seasonal fluctuations and drought effects on soil amoeba population size and genetic heterogeneity.

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TABLE 1. SOIL CHEMISTRY:\*

| ELEM.           | DATE*** | SITE/HORIZON** |           |           |         |         |         |
|-----------------|---------|----------------|-----------|-----------|---------|---------|---------|
|                 |         | CO             | AO        | GO        | CM      | AM      | GM      |
| P               | 1       | 42,41          | 30,29     | 26,28     | 69,62   | 14,13   | 26,27   |
|                 | 2       | 44,49          | 29,28     | 31,28     | 60,65   | 13,17   | 20,20   |
| K               | 1       | 115,111        | 99, 98    | 107,111   | 44,44   | 36,36   | 44,44   |
|                 | 2       | 103, 84        | 92, 88    | 99,107    | 44,40   | 40,36   | 40,40   |
| Ca              | 1       | 1720,1640      | 2160,2040 | 1800,1840 | 724,686 | 838,876 | 838,762 |
|                 | 2       | 1640,1334      | 2000,2000 | 1840,1840 | 648,648 | 991,838 | 724,762 |
| Mg              | 1       | 108,122        | 153,172   | 143,164   | 84,80   | 88,91   | 81,80   |
|                 | 2       | 119,115        | 139,160   | 153,168   | 73,64   | 84,79   | 76,80   |
| NO <sub>3</sub> | 1       | 7.6,7.1        | 7.5,8.2   | 7.5,8.3   | 4.1,4.1 | 3.8,4.0 | 4.1,5.0 |
|                 | 2       | 7.8,7.3        | 7.5,8.0   | 8.0,8.6   | 4.2,4.5 | 4.8,4.1 | 4.0,4.8 |
| %Org.N.         | 1       | 6.6,6.6        | 7.8,8.0   | 6.6,7.0   | 1.2,1.5 | 1.5,1.5 | 1.7,1.7 |
|                 | 2       | 6.8,5.2        | 7.2,6.6   | 7.6,6.8   | 1.5,1.4 | 1.8,1.7 | 1.5,1.4 |

\*Performed by Michigan State University Soil Testing Laboratory, data expressed as ppm except for %Org.N.

\*\*SITE: C, control; A, antenna; G, ground.  
HORIZON: O, organic; M, mineral

\*\*\*Data was obtained June 25 and Aug 22, 1990, each of which were taken from 20 random samples.



TABLE 2. SOIL CHEMISTRY 2X ANOVA, between sites and dates:

| ELEMENT         |           | ORGANIC |         |          | MINERAL  |           |
|-----------------|-----------|---------|---------|----------|----------|-----------|
|                 |           | D.F.    | M.S.    | F        | M.S.     | F         |
| P               | Site      | 2       | 315.75  | 92.41 ** | 2811.08  | 366.66 ** |
|                 | Date      | 1       | 14.08   | 4.12 NS  | 21.33    | 2.78 NS   |
|                 | Interact. | 2       | 9.08    | 2.66 NS  | 16.08    | 2.09 NS   |
|                 | Error     | 6       | 3.42    |          | 7.67     |           |
| K               | Site      | 2       | 151.08  | 3.82 NS  | 41.33    | 15.5 **   |
|                 | Date      | 1       | 385.33  | 9.76 *   | 5.33     | 2 NS      |
|                 | Interact. | 2       | 51.58   | 1.31 NS  | 9.33     | 3.5 NS    |
|                 | Error     | 6       | 39.5    |          | 2.57     |           |
| Ca              | Site      | 2       | 217856  | 22.53 ** | 43909.08 | 15.72 **  |
|                 | Date      | 1       | 24843   | 2.56 NS  | 1064.08  | 0.38 NS   |
|                 | Interact. | 2       | 11403   | 1.18 NS  | 4370.08  | 1.56 NS   |
|                 | Error     | 6       | 9669.67 |          | 2793.08  |           |
| Mg              | Site      | 2       | 2188    | 15.63 ** | 106.75   | 8.66 *    |
|                 | Date      | 1       | 5.33    | 0.04 NS  | 192.     | 15.56 **  |
|                 | Interact  | 2       | 108.33  | 0.77 NS  | 30.25    | 2.45 NS   |
|                 | Error     | 6       | 140     |          | 12.33    |           |
| NO <sub>3</sub> | Site      | 2       | 0.42    | 2.26 NS  | 0.01     | 0.06 NS   |
|                 | Date      | 1       | 0.08    | 0.44 NS  | 0.02     | 0.12 NS   |
|                 | Interact. | 2       | 0.06    | 0.34 NS  | 0.28     | 1.9 NS    |
|                 | Error     | 6       | 0.18    |          | 0.14     |           |
| % Org.N         | Site      | 2       | 1.24    | 3.96 NS  | 0.056    | 5.56 *    |
|                 | Date      | 1       | 0.48    | 1.53 NS  | 0.003    | 0.33 NS   |
|                 | Interact. | 2       | 0.52    | 1.66 NS  | 0.066    | 6.58 *    |
|                 | Error     | 6       | 0.31    |          | 0.01     |           |

\* = 5% significance level

\*\* = 1% significance level

TABLE 3. SOIL pH:

| DATE   | SITE                 | HORIZON              | MEAN $\pm$ S.E. (n = 10) |
|--------|----------------------|----------------------|--------------------------|
| 26 JUN | Control <sup>1</sup> | Organic              | 6.24 $\pm$ 0.15          |
|        |                      | Mineral              | 6.72 $\pm$ 0.15          |
|        | Antenna              | Organic              | 6.63 $\pm$ 0.08          |
|        |                      | Mineral              | 6.64 $\pm$ 0.07          |
|        | Ground               | Organic              | 6.51 $\pm$ 0.16          |
|        |                      | Mineral              | 6.65 $\pm$ 0.12          |
| 23 AUG | Control              | Organic <sup>2</sup> | 6.19 $\pm$ 0.18          |
|        |                      | Mineral              | 6.44 $\pm$ 0.15          |
|        | Antenna              | Organic <sup>2</sup> | 6.76 $\pm$ 0.08          |
|        |                      | Mineral              | 6.52 $\pm$ 0.12          |
|        | Ground               | Organic <sup>2</sup> | 6.25 $\pm$ 0.13          |
|        |                      | Mineral              | 6.5 $\pm$ 0.13           |

TWO WAY ANOVA, Site, Horizon for each date:

| DATE  |             | DF | MS     | F        |
|-------|-------------|----|--------|----------|
| 26JUN | Site        | 2  | 0.1235 | 0.7545   |
|       | Horizon     | 1  | 0.6615 | 4.0413 * |
|       | Interaction | 2  | 0.2945 | 1.7992   |
|       | Error       | 54 | 0.1637 |          |
| 23AUG | Site        | 2  | 0.5982 | 3.3238 * |
|       | Horizon     | 1  | 0.1127 | 0.6261   |
|       | Interaction | 2  | 0.4002 | 2.2236   |
|       | Error       | 54 | 0.1800 |          |

ONE WAY ANOVA: footnotes indicated above refer to these

| DATE               | SITE    | HORIZON | GROUPS | DF | MS    | F       |
|--------------------|---------|---------|--------|----|-------|---------|
| 26JUN <sup>1</sup> | Control | Org/Min | among  | 1  | 1.152 | 5.058 * |
|                    |         |         | within | 18 | 0.228 |         |
| 23AUG <sup>2</sup> | 3 sites | Organic | among  | 2  | 0.981 | 5.41 *  |
|                    |         |         | within | 27 | 0.181 |         |

\* = 5% significance level

TABLE 4. Total counts from 8 samples per horizon/site:

| SITE    | HORIZON | DATE  | MEAN #/g soil $\pm$ S.E.*<br>(log#) | MEAN**  |
|---------|---------|-------|-------------------------------------|---------|
| Control | Organic | 6/19  | 4.5119 $\pm$ 0.2888                 | 14,683  |
|         |         | 7/16  | 4.3348 $\pm$ 0.2441                 | 68,593  |
|         |         | 8/14  | 4.6732 $\pm$ 0.1320                 | 67,483  |
|         |         | 9/17  | 5.5479 $\pm$ 0.1286                 | 449,366 |
|         |         | 10/14 | 5.3436 $\pm$ 0.0555                 | 233,526 |
|         | Mineral | 6/19  | 3.6791 $\pm$ 0.1452                 | 6,597   |
|         |         | 7/16  | 3.9061 $\pm$ 0.1178                 | 10,081  |
|         |         | 8/14  | 4.6378 $\pm$ 0.0952                 | 51,350  |
|         |         | 9/17  | 4.8346 $\pm$ 0.0777                 | 76,493  |
|         |         | 10/14 | 4.8097 $\pm$ 0.2020                 | 124,118 |
| Antenna | Organic | 6/19  | 4.1527 $\pm$ 0.1671                 | 24,121  |
|         |         | 7/16  | 4.7737 $\pm$ 0.1350                 | 79,835  |
|         |         | 8/14  | 4.9369 $\pm$ 0.1036                 | 107,769 |
|         |         | 9/17  | 5.1380 $\pm$ 0.0915                 | 161,554 |
|         |         | 10/14 | 5.6321 $\pm$ 0.1600                 | 651,927 |
|         | Mineral | 6/19  | 3.5838 $\pm$ 0.1593                 | 5,574   |
|         |         | 7/16  | 4.2308 $\pm$ 0.0716                 | 18,623  |
|         |         | 8/14  | 4.5975 $\pm$ 0.0967                 | 48,736  |
|         |         | 9/17  | 4.2191 $\pm$ 0.2449                 | 27,756  |
|         |         | 10/14 | 4.9791 $\pm$ 0.0753                 | 106,446 |
| Ground  | Organic | 6/19  | 3.8654 $\pm$ 0.1527                 | 10,969  |
|         |         | 7/16  | 4.5587 $\pm$ 0.0758                 | 40,719  |
|         |         | 8/14  | 4.8353 $\pm$ 0.1154                 | 83,484  |
|         |         | 9/17  | 4.9736 $\pm$ 0.0918                 | 113,196 |
|         |         | 10/14 | 5.3623 $\pm$ 0.0569                 | 242,543 |
|         | Mineral | 6/19  | 3.5524 $\pm$ 0.0828                 | 4,027   |
|         |         | 7/16  | 3.9625 $\pm$ 0.1462                 | 12,915  |
|         |         | 8/14  | 4.6473 $\pm$ 0.1492                 | 63,241  |
|         |         | 9/17  | 4.5940 $\pm$ 0.1569                 | 57,468  |
|         |         | 10/14 | 4.6801 $\pm$ 0.0665                 | 51,737  |

\* Mean expressed as  $\log_{10}$  number, used to calculate analysis of variance (Table 4B).

\*\* Mean calculated from arithmetic data which will differ from converting the mean of log data to an arithmetic figure. The log of the arithmetic mean will not be the same as the mean of the log transformed data.

TABLE 4A. Cyst counts from 8 samples per horizon/site:

| SITE    | HORIZON | DATE  | MEAN #/g soil $\pm$ S.E.*<br>(log#) | MEAN**  |
|---------|---------|-------|-------------------------------------|---------|
| Control | Organic | 6/19  | 3.8695 $\pm$ 0.1179                 | 9,364   |
|         |         | 7/16  | 4.7692 $\pm$ 0.1047                 | 74,428  |
|         |         | 8/14  | 3.9928 $\pm$ 0.0809                 | 11,102  |
|         |         | 9/17  | 5.5601 $\pm$ 0.0670                 | 391,725 |
|         |         | 10/14 | 4.2924 $\pm$ 0.0972                 | 23,056  |
|         | Mineral | 6/19  | 3.5718 $\pm$ 0.1305                 | 5,007   |
|         |         | 7/16  | 4.0150 $\pm$ 0.1433                 | 17,817  |
|         |         | 8/14  | 3.8390 $\pm$ 0.1439                 | 10,130  |
|         |         | 9/17  | 4.5204 $\pm$ 0.0638                 | 35,776  |
|         |         | 10/14 | 3.3454 $\pm$ 0.0642                 | 2,399   |
| Antenna | Organic | 6/19  | 3.3358 $\pm$ 0.0765                 | 2,402   |
|         |         | 7/16  | 4.5693 $\pm$ 0.1979                 | 74,597  |
|         |         | 8/14  | 4.6546 $\pm$ 0.0800                 | 49,724  |
|         |         | 9/17  | 4.7147 $\pm$ 0.1310                 | 72,677  |
|         |         | 10/14 | 4.7690 $\pm$ 0.2613                 | 117,029 |
|         | Mineral | 6/19  | 3.5747 $\pm$ 0.1227                 | 5,072   |
|         |         | 7/16  | 3.7022 $\pm$ 0.1785                 | 11,940  |
|         |         | 8/14  | 4.0618 $\pm$ 0.2124                 | 35,706  |
|         |         | 9/17  | 4.2752 $\pm$ 0.1166                 | 24,979  |
|         |         | 10/14 | 3.4814 $\pm$ 0.0641                 | 3,289   |
| Ground  | Organic | 6/19  | 3.6389 $\pm$ 0.1466                 | 6,729   |
|         |         | 7/16  | 4.9733 $\pm$ 0.1166                 | 116,044 |
|         |         | 8/14  | 4.4765 $\pm$ 0.1507                 | 42,623  |
|         |         | 9/17  | 5.0615 $\pm$ 0.1154                 | 143,452 |
|         |         | 10/14 | 4.5067 $\pm$ 0.1623                 | 55,065  |
|         | Mineral | 6/19  | 3.7880 $\pm$ 0.1308                 | 7,884   |
|         |         | 7/16  | 4.1989 $\pm$ 0.1237                 | 22,177  |
|         |         | 8/14  | 3.7018 $\pm$ 0.1332                 | 6,771   |
|         |         | 9/17  | 4.2890 $\pm$ 0.1839                 | 31,020  |
|         |         | 10/14 | 3.5688 $\pm$ 0.1094                 | 4,567   |

\* Mean expressed as  $\log_{10}$  number, used to calculate analysis of variance (Table 4B).

\*\* Mean calculated from arithmetic data which will differ from converting the mean of log data to an arithmetic figure.

TABLE 4B. One-way analysis of variance by date and horizon. Data log transformed (see Table 4 &amp; 4A).

| HORIZON | DATE   | GROUPS | DF         | TOTAL COUNT |           |    |        |  |      |        |    |        |
|---------|--------|--------|------------|-------------|-----------|----|--------|--|------|--------|----|--------|
|         |        |        |            | MS          | F         |    |        |  |      |        |    |        |
| ORGANIC | 6/19   | among  | 2          | 0.8393      | 2.3374 NS |    |        |  |      |        |    |        |
|         |        | within | 21         | 0.3591      |           |    |        |  |      |        |    |        |
|         | 7/16   | among  | 2          | 0.3854      | 1.7294 NS |    |        |  |      |        |    |        |
|         |        | within | 21         | 0.2229      |           |    |        |  |      |        |    |        |
|         | 8/14   | among  | 2          | 0.1414      | 1.2782 NS |    |        |  |      |        |    |        |
|         |        | within | 21         | 0.1106      |           |    |        |  |      |        |    |        |
|         | 9/17   | among  | 2          | 0.6997      | 7.8716 *  |    |        |  |      |        |    |        |
|         |        | within | 21         | 0.0889      |           |    |        |  |      |        |    |        |
| 10/14   | among  | 2      | 0.2084     | 2.4493 NS   |           |    |        |  |      |        |    |        |
|         | within | 21     | 0.0851     |             |           |    |        |  |      |        |    |        |
| MINERAL | 6/19   | among  | 2          | 0.0348      | 0.2450 NS |    |        |  |      |        |    |        |
|         |        | within | 21         | 0.1422      |           |    |        |  |      |        |    |        |
|         | 7/16   | among  | 2          | 0.2409      | 2.2373 NS |    |        |  |      |        |    |        |
|         |        | within | 21         | 0.1077      |           |    |        |  |      |        |    |        |
|         | 8/14   | among  | 2          | 0.0050      | 0.0508 NS |    |        |  |      |        |    |        |
|         |        | within | 21         | 0.1085      |           |    |        |  |      |        |    |        |
|         | 9/17   | among  | 2          | 0.7699      | 3.1862 NS |    |        |  |      |        |    |        |
|         |        | within | 21         | 0.2416      |           |    |        |  |      |        |    |        |
| 10/14   | among  | 2      | 0.1799     | 1.3249 NS   |           |    |        |  |      |        |    |        |
|         | within | 21     | 0.1358     |             |           |    |        |  |      |        |    |        |
| ORGANIC |        |        | CYST COUNT |             |           |    |        |  |      |        |    |        |
|         |        |        | 6/19       | among       |           | 2  | 0.5732 |  |      |        |    |        |
|         |        |        |            | within      |           | 21 | 0.1100 |  |      |        |    |        |
|         |        |        | 7/17       | among       |           | 2  | 0.3264 |  |      |        |    |        |
|         |        |        |            | within      |           | 21 | 0.1699 |  |      |        |    |        |
|         |        |        | 8/14       | among       |           | 2  | 0.9383 |  |      |        |    |        |
|         |        |        |            | within      |           | 21 | 0.0951 |  |      |        |    |        |
|         |        |        | 9/12       | among       |           | 2  | 1.3609 |  |      |        |    |        |
|         |        |        |            | within      |           | 21 | 0.0932 |  |      |        |    |        |
|         |        |        | 10/15      | among       |           | 2  | 0.4557 |  |      |        |    |        |
|         |        |        |            | within      |           | 21 | 0.2774 |  |      |        |    |        |
|         |        |        | MINERAL    |             |           |    |        |  |      |        |    |        |
|         |        |        |            |             |           |    |        |  | 6/19 | among  | 2  | 0.1230 |
|         |        |        |            |             |           |    |        |  |      | within | 21 | 0.1312 |
|         |        |        |            |             |           |    |        |  | 7/17 | among  | 2  | 0.5044 |
|         |        |        |            |             |           |    |        |  |      | within | 21 | 0.1805 |
| 8/14    | among  | 2      |            |             | 0.2642    |    |        |  |      |        |    |        |
|         | within | 21     |            |             | 0.2229    |    |        |  |      |        |    |        |
| 9/12    | among  | 2      |            |             | 0.1519    |    |        |  |      |        |    |        |
|         | within | 21     |            |             | 0.1373    |    |        |  |      |        |    |        |
| 10/15   | among  | 2      |            |             | 0.1014    |    |        |  |      |        |    |        |
|         | within | 21     | 0.0539     |             |           |    |        |  |      |        |    |        |

\* = 5% significance level

\*\* = 1% significance level

TABLE 5. SOIL MOISTURE (% w/w)<sup>1</sup>

| HORIZON | CONTROL SITE |            | ANTENNA SITE |            | GROUND SITE |            |
|---------|--------------|------------|--------------|------------|-------------|------------|
|         | ORG          | MIN        | ORG          | MIN        | ORG         | MIN        |
| DATE    |              |            |              |            |             |            |
| 6/19    | 31.4 ± 4.1   | 14.3 ± 2.4 | 32.4 ± 2.8   | 16.9 ± 3.5 | 35.1 ± 5.7  | 18.1 ± 1.3 |
| 7/16    | 31.5 ± 9.2   | 11.5 ± 1.3 | 26.6 ± 4.9   | 15.2 ± 8   | 30 ± 7.5    | 15.8 ± 1.4 |
| 8/14    | 22.9 ± 3.7   | 7.6 ± 0.8  | 25.5 ± 4.2   | 13.8 ± 2.9 | 25 ± 5.2    | 13.7 ± 2.3 |
| 9/17    | 49 ± 7.8     | 15.6 ± 4.8 | 44 ± 8.8     | 6.3 ± 2.6  | 38 ± 3.5    | 12.7 ± 2.1 |
| 10/14   | 52.5 ± 10.9  | 17 ± 4.5   | 43 ± 8       | 18.5 ± 2.3 | 33.5 ± 1.8  | 18.4 ± 1.9 |

ONE WAY ANOVA (between sites):

| ORGANIC       |      |          | MINERAL |         |  |
|---------------|------|----------|---------|---------|--|
| Date          | D.F. | M.S.     | D.F.    | M.S.    |  |
| 6/19 Between  | 2    | 29.31    | 2       | 30.19   |  |
| Within        | 21   | 19.05    | 21      | 6.57    |  |
| F=            |      | 1.54 NS  |         | 4.59 *  |  |
| 7/16 Between  | 2    | 50.43    | 2       | 43.39   |  |
| Within        | 21   | 54.97    | 21      | 22.55   |  |
| F=            |      | 0.92 NS  |         | 1.92 NS |  |
| 8/14 Between  | 2    | 15.22    | 2       | 100.88  |  |
| Within        | 21   | 19.46    | 21      | 4.78    |  |
| F=            |      | 0.78 NS  |         | 21.1 ** |  |
| 9/17 Between  | 2    | 242.66   | 2       | 29.15   |  |
| Within        | 21   | 50.17    | 21      | 11.4    |  |
| F=            |      | 4.84 *   |         | 2.56 NS |  |
| 10/14 Between | 2    | 722      | 2       | 5.63    |  |
| Within        | 21   | 62.02    | 21      | 9.72    |  |
| F=            |      | 11.64 ** |         | 0.58 NS |  |

<sup>1</sup> = mean ± S.D. (n=8)

\* = 5% significance level

\*\* = 1% significance level

TABLE 6. Regression calculations for growth of Acanthamoeba polyphaga in soil submersible culture vessels, data log transformed.

Details of electric currents in vessels given in Table 7. Actual operating schedules of the ELF antenna will be collated from IITRI data.

| *Date   | Experiment*      | Slope** | 95% Confidence Limits***     |
|---------|------------------|---------|------------------------------|
| 6/11/90 | E-Field, control | 0.03139 | L1 = 0.00634 / L2 = 0.06912  |
|         | " , antenna      | 0.02797 | L1 = 0.00694 / L2 = 0.04901  |
|         | " , ground       | 0.03114 | L1 = -0.04642 / L2 = 0.10869 |
|         | Current, control | 0.02895 | L1 = -0.05409 / L2 = 0.11199 |
|         | " , antenna      | 0.02641 | L1 = -0.03884 / L2 = 0.09165 |
|         | " , ground       | 0.03155 | L1 = 0.01008 / L2 = 0.05301  |
| 7/10/90 | E-Field, control | 0.01542 | L1 = -0.00292 / L2 = 0.03371 |
|         | " , antenna      | 0.01355 | L1 = 0.00423 / L2 = 0.02287  |
|         | " , ground       | 0.01338 | L1 = 0.00021 / L2 = 0.02696  |
|         | Current, control | 0.01755 | L1 = 0.01017 / L2 = 0.02492  |
|         | " , antenna      | 0.01213 | L1 = 0.00181 / L2 = 0.02244  |
|         | " , ground       | 0.01428 | L1 = -0.00347 / L2 = 0.03204 |
| 7/30/90 | E-Field, control | 0.01811 | L1 = 0.01568 / L2 = 0.02464  |
|         | " , antenna      | 0.01927 | L1 = 0.01203 / L2 = 0.02651  |
|         | " , ground       | 0.01860 | L1 = 0.01262 / L2 = 0.02458  |
|         | Current, control | 0.01984 | L1 = 0.01559 / L2 = 0.02408  |
|         | " , antenna      | 0.01841 | L1 = 0.01588 / L2 = 0.02093  |
|         | " , ground       | 0.01838 | L1 = 0.01059 / L2 = 0.02616  |

\* Three replicate experiments were done both E-field and Current density experiments at each site. Duplicate counts were done on each culture.

\*\* Mean generation times were: 9 to 24 hr.

\*\*\* For the slope of the curve; Bonferoni T-tests of slopes:

|         |                     | E. Field | Current Density |
|---------|---------------------|----------|-----------------|
| 6/11/90 | Control vs. Antenna | 1.00467  | 0.30060         |
|         | Control vs. Ground  | 0.03734  | 0.38500         |
|         | Antenna vs. Ground  | 0.50005  | 0.48100         |
| 7/10/90 | Control vs. Antenna | 0.42818  | 1.83853         |
|         | Control vs. Ground  | 0.38600  | 0.73079         |
|         | Antenna vs. Ground  | 0.45065  | 0.45075         |
| 7/30/90 | Control vs. Antenna | 0.51254  | 1.24954         |
|         | Control vs. Ground  | 0.24034  | 0.70934         |
|         | Antenna vs. Ground  | 0.30576  | 0.01495         |

14 d.f. for error; no significant differences were noted.

TABLE 7a. Culture cell current densities and E-field voltages measured during growth experiments (Table 6) for June 11, 1990.

| Electrodes <sup>1</sup> | Voc (mv) | Vcl (mv) <sup>4</sup> | Vr (mv) | Ecl (mv/m) <sup>2</sup> | Jcl (ma/m <sup>2</sup> ) <sup>3</sup> |
|-------------------------|----------|-----------------------|---------|-------------------------|---------------------------------------|
| Control, CD:            |          |                       |         |                         |                                       |
| 1                       | 1.64     | *                     | 1.65    | *                       | 0.004                                 |
| 2                       | 1.44     | *                     | 1.44    | *                       | 0.004                                 |
| 3                       | 1.77     | *                     | 1.80    | *                       | 0.005                                 |
| Control, EF:            |          |                       |         |                         |                                       |
| 1                       | 2.43     | 0.21                  | *       | 1.86                    | *                                     |
| 2                       | 1.94     | 0.21                  | *       | 1.86                    | *                                     |
| 3                       | 2.36     | 0.21                  | *       | 1.86                    | *                                     |
| Antenna, CD:            |          |                       |         |                         |                                       |
| 1                       | 52       | *                     | 51      | *                       | 0.13                                  |
| 2                       | 46       | *                     | 44      | *                       | 0.11                                  |
| 3                       | 56       | *                     | 55      | *                       | 0.14                                  |
| Antenna, EF:            |          |                       |         |                         |                                       |
| 1                       | 59       | 6.5                   | *       | 57.2                    | *                                     |
| 2                       | 95       | 6.6                   | *       | 59.5                    | *                                     |
| 3                       | 59       | 6.6                   | *       | 58.6                    | *                                     |
| Ground, CD:             |          |                       |         |                         |                                       |
| 1                       | 19       | *                     | 20      | *                       | 0.052                                 |
| 2                       | 23       | *                     | 13      | *                       | 0.033                                 |
| 3                       | 23       | *                     | 20      | *                       | 0.052                                 |
| Ground, EF:             |          |                       |         |                         |                                       |
| 1                       | 26       | 3.40                  | *       | 30.1                    | *                                     |
| 2                       | 28       | 3.50                  | *       | 31.0                    | *                                     |
| 3                       | 14       | 3.60                  | *       | 31.9                    | *                                     |

<sup>1</sup>CD = current density cultures; EF = E-field cultures.

<sup>2</sup>E-field: Ecl (mv/m) = Vcl / 0.113 (length between electrodes).

<sup>3</sup>Current density: Jcl (mA/m<sup>2</sup>) = Vr / R \* xs. area of cl (m<sup>2</sup>), where R (ohms) = 2.5 \* 10<sup>4</sup> for J; 100 for E. Area of cl varied depending on submerged electrode area; for this experiment it was 1.57 \* 10<sup>-4</sup> m<sup>2</sup>.

<sup>4</sup>Vcl for EF adjusted to this value, calculated: E (1m) \* 0.113 (length between electrodes).

\*Value too low for meter to accurately record.



TABLE 7b. Culture cell current densities and E-field voltages measured during growth experiments (Table 6) for July 10, 1990.

| Electrodes <sup>1</sup> | Voc (mv) | Vcl (mv) <sup>4</sup> | Vr (mv) | Ecl (mv/m) <sup>2</sup> | Jcl (ma/m <sup>2</sup> ) <sup>3</sup> |
|-------------------------|----------|-----------------------|---------|-------------------------|---------------------------------------|
| Control, CD:            |          |                       |         |                         |                                       |
| 1                       | 1.4      | *                     | 1.35    | *                       | 0.003                                 |
| 2                       | 1.2      | *                     | 1.26    | *                       | 0.003                                 |
| 3                       | 1.4      | *                     | 1.43    | *                       | 0.004                                 |
| Control, EF:            |          |                       |         |                         |                                       |
| 1                       | 1.9      | 0.16                  | *       | 1.4                     | *                                     |
| 2                       | 1.6      | 0.16                  | *       | 1.4                     | *                                     |
| 3                       | 1.9      | 0.16                  | *       | 1.4                     | *                                     |
| Antenna, CD:            |          |                       |         |                         |                                       |
| 1                       | 49       | *                     | 48      | *                       | 0.12                                  |
| 2                       | 45       | *                     | 44      | *                       | 0.11                                  |
| 3                       | 54       | *                     | 54      | *                       | 0.14                                  |
| Antenna, EF:            |          |                       |         |                         |                                       |
| 1                       | 59       | 6.4                   | *       | 56.6                    | *                                     |
| 2                       | 92       | 6.7                   | *       | 59.3                    | *                                     |
| 3                       | 60       | 6.5                   | *       | 57.5                    | *                                     |
| Ground, CD:             |          |                       |         |                         |                                       |
| 1                       | 19       | *                     | 21      | *                       | 0.055                                 |
| 2                       | 19       | *                     | 20      | *                       | 0.051                                 |
| 3                       | 22       | *                     | 24      | *                       | 0.061                                 |
| Ground, EF:             |          |                       |         |                         |                                       |
| 1                       | 22       | 3.1                   | *       | 27.5                    | *                                     |
| 2                       | 25       | 2.7                   | *       | 24.1                    | *                                     |
| 3                       | 21       | 3.3                   | *       | 29.6                    | *                                     |

<sup>1</sup>CD = current density cultures; EF = E-field cultures.

<sup>2</sup>E-field:  $Ecl (mv/m) = Vcl / 0.113$  (length between electrodes).

<sup>3</sup>Current density:  $Jcl (mA/m^2) = Vr / R * xs. \text{ area of } cl (m^2)$ , where  $R (ohms) = 2.5 * 10^6$  for J; 100 for E. Area of cl varied depending on submerged electrode area; for this experiment it was  $1.57 * 10^{-4} m^2$ .

<sup>4</sup>Vcl for EF adjusted to this value, calculated:  $E (1m) * 0.113$  (length between electrodes).

\*Value too low for meter to accurately record.

TABLE 7c. Culture cell current densities and E-field voltages measured during growth experiments (Table 6) for July 30, 1990.

| Electrodes <sup>1</sup> | Voc (mv) | Vcl (mv) <sup>4</sup> | Vr (mv) | Ecl (mv/m) <sup>2</sup> | Jcl (ma/m <sup>2</sup> ) <sup>3</sup> |
|-------------------------|----------|-----------------------|---------|-------------------------|---------------------------------------|
| Control, CD:            |          |                       |         |                         |                                       |
| 1                       | 2        | *                     | 2.1     | *                       | 0.005                                 |
| 2                       | 2        | *                     | 1.8     | *                       | 0.005                                 |
| 3                       | 2        | *                     | 2.2     | *                       | 0.006                                 |
| Control, EF:            |          |                       |         |                         |                                       |
| 1                       | 3        | 0.26                  | *       | 2.3                     | *                                     |
| 2                       | 2        | 0.26                  | *       | 2.3                     | *                                     |
| 3                       | 3        | 2.8                   | *       | 25                      | *                                     |
| Antenna, CD:            |          |                       |         |                         |                                       |
| 1                       | 52       | *                     | 51      | *                       | 0.13                                  |
| 2                       | 46       | *                     | 46      | *                       | 0.12                                  |
| 3                       | 53       | *                     | 53      | *                       | 0.14                                  |
| Antenna, EF:            |          |                       |         |                         |                                       |
| 1                       | 61       | 5.7                   | *       | 50.2                    | *                                     |
| 2                       | 89       | 6.3                   | *       | 55.3                    | *                                     |
| 3                       | 61       | 6.4                   | *       | 56.5                    | *                                     |
| Ground, CD:             |          |                       |         |                         |                                       |
| 1                       | 19       | *                     | 24      | *                       | 0.06                                  |
| 2                       | 24       | *                     | 23      | *                       | 0.06                                  |
| 3                       | 25       | *                     | 22      | *                       | 0.06                                  |
| Ground, EF:             |          |                       |         |                         |                                       |
| 1                       | 24       | 3.1                   | *       | 27.3                    | *                                     |
| 2                       | 25       | 2.9                   | *       | 25.8                    | *                                     |
| 3                       | 17       | 3.1                   | *       | 27.4                    | *                                     |

<sup>1</sup>CD = current density cultures; EF = E-field cultures.

<sup>2</sup>E-field: Ecl (mv/m) = Vcl / 0.113 (length between electrodes).

<sup>3</sup>Current density: Jcl (mA/m<sup>2</sup>) = Vr / R \* xs. area of cl (m<sup>2</sup>), where R (ohms) =  $2.5 \times 10^6$  for J; 100 for E. Area of cl varied depending on submerged electrode area; for this experiment it was  $1.57 \times 10^{-4}$  m<sup>2</sup>.

<sup>4</sup>Vcl for EF adjusted to this value, calculated: E (1m) \* 0.113 (length between electrodes).

\*Value too low for meter to accurately record.

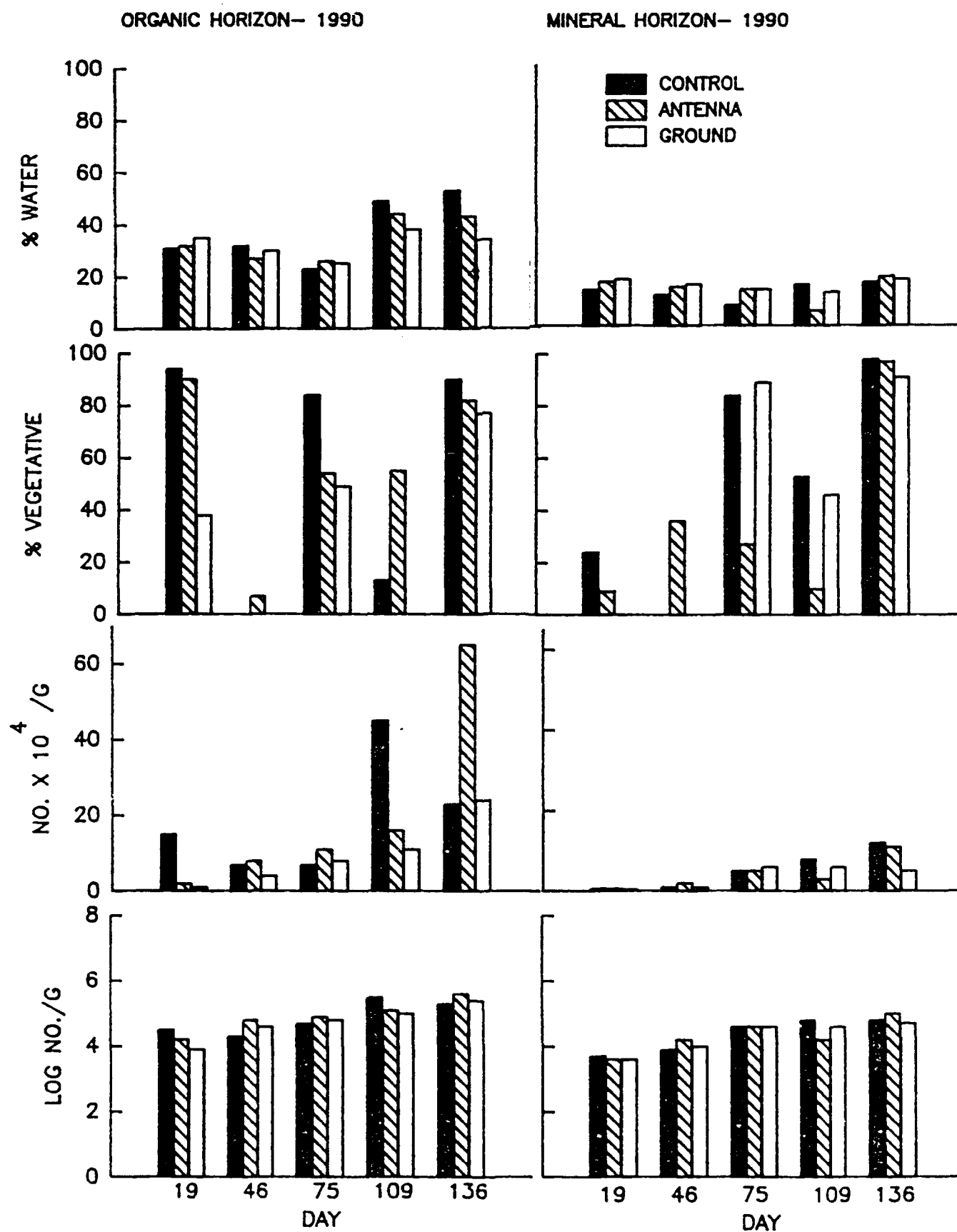
TABLE 8. Bacterial counts at control site.

| DATE  | HORIZON | LOG MEAN NO. $\pm$ Std. Dev. |
|-------|---------|------------------------------|
| 15AUG | Organic | 9.5234 $\pm$ 0.0367          |
|       | Mineral | 9.0545 $\pm$ 0.0367          |
| 15SEP | Organic | 9.5926 $\pm$ 0.0418          |
|       | Mineral | 9.1007 $\pm$ 0.0564          |

TWO-WAY AMOVA, date, horizon:

|             | D.F. | M.S.   | F         |
|-------------|------|--------|-----------|
| Horizon     | 1    | 7.4585 | 3799.29** |
| Date        | 1    | 0.1075 | 54.76**   |
| Interaction | 1    | 0.0043 | 2.17      |
| Error       | 126  | 0.0020 |           |

\*\* = 1% significance level



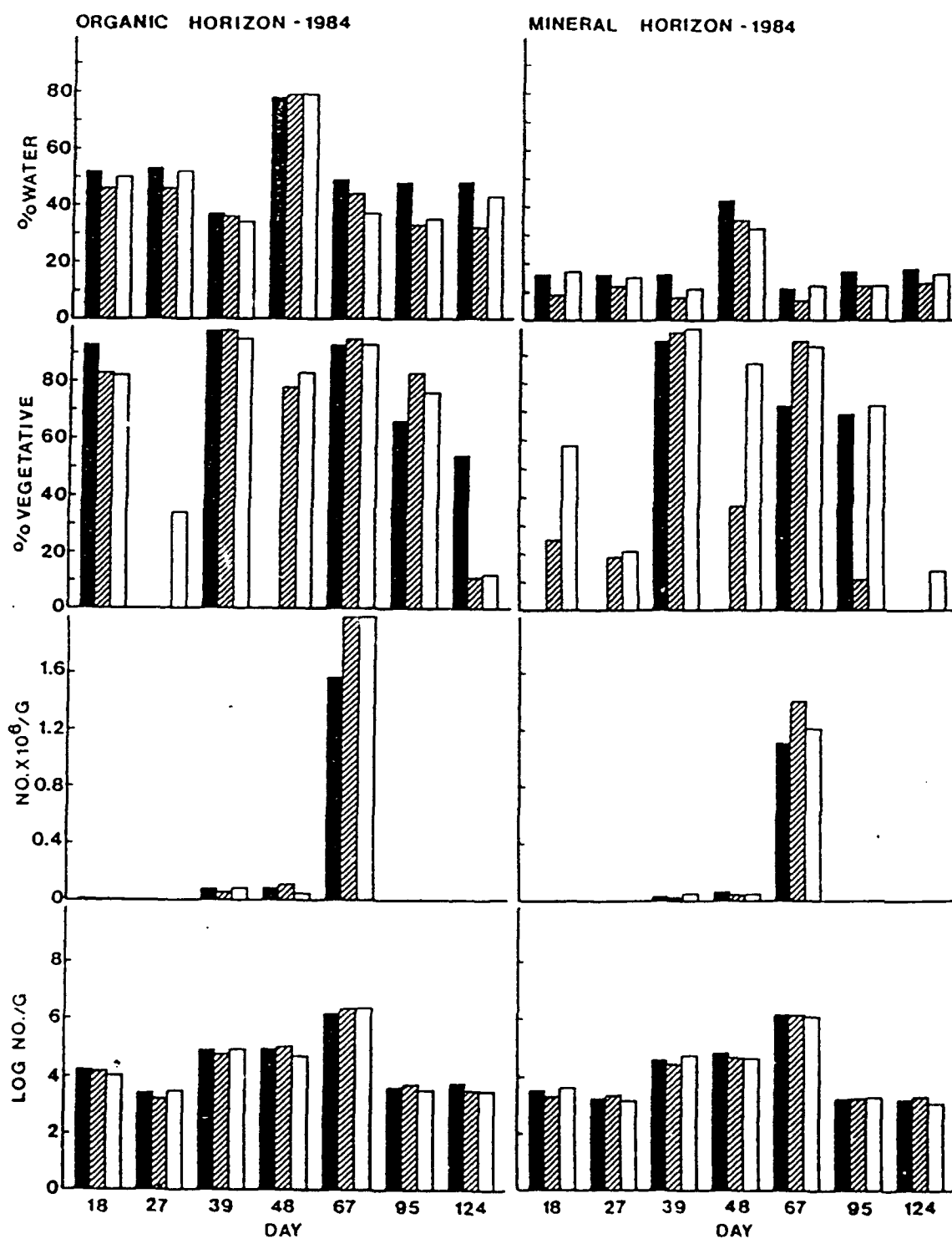
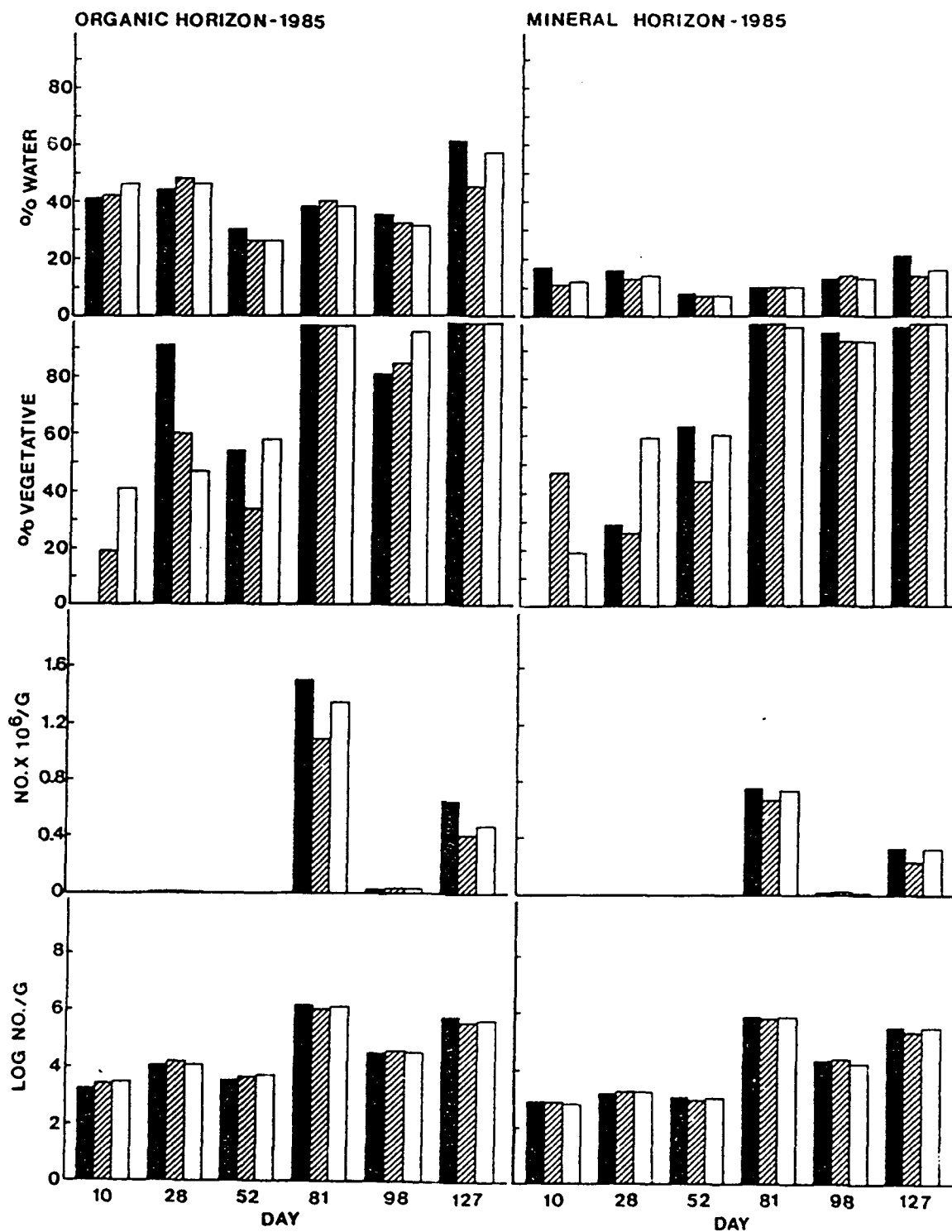
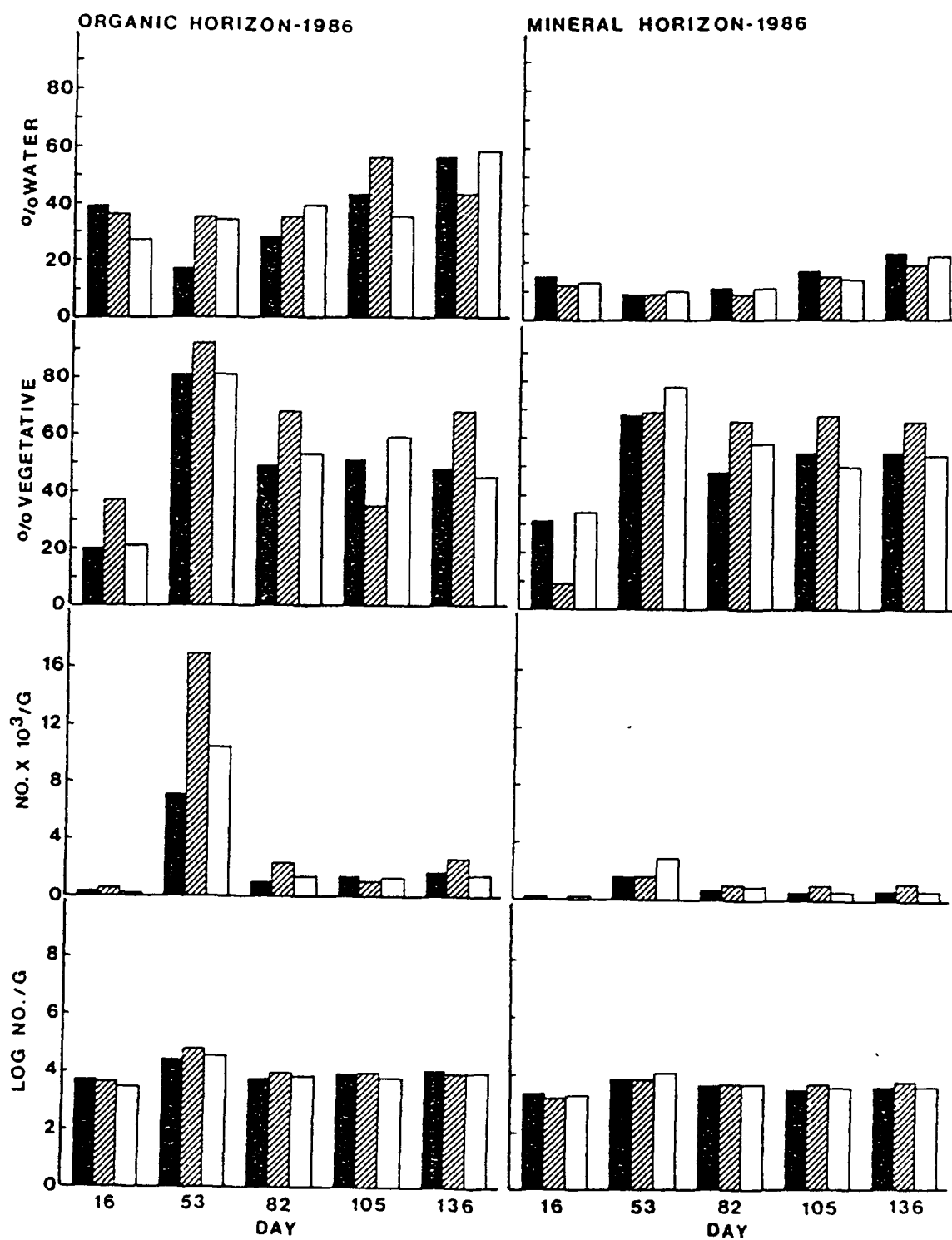
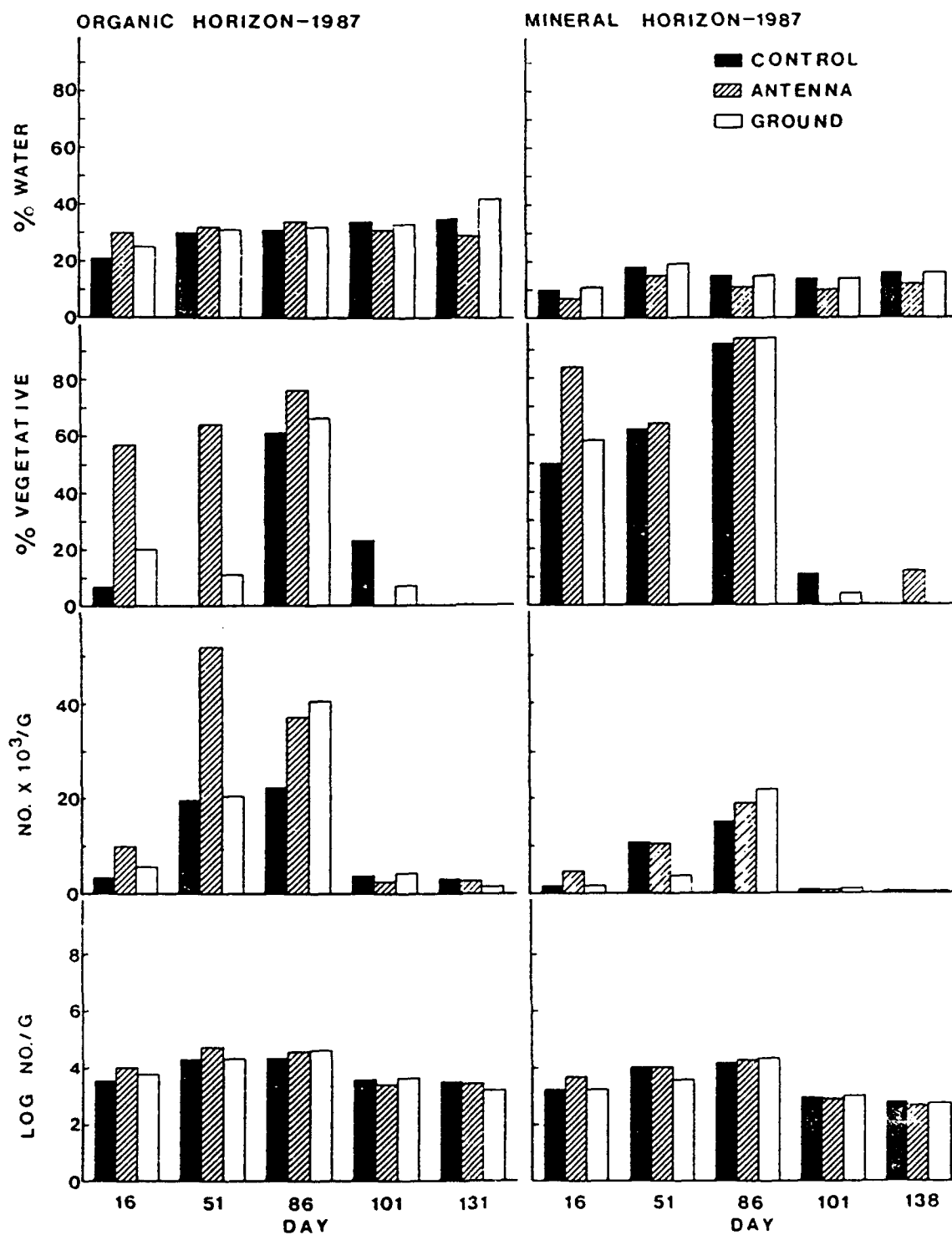


Figure 1C. Summary of previous years.









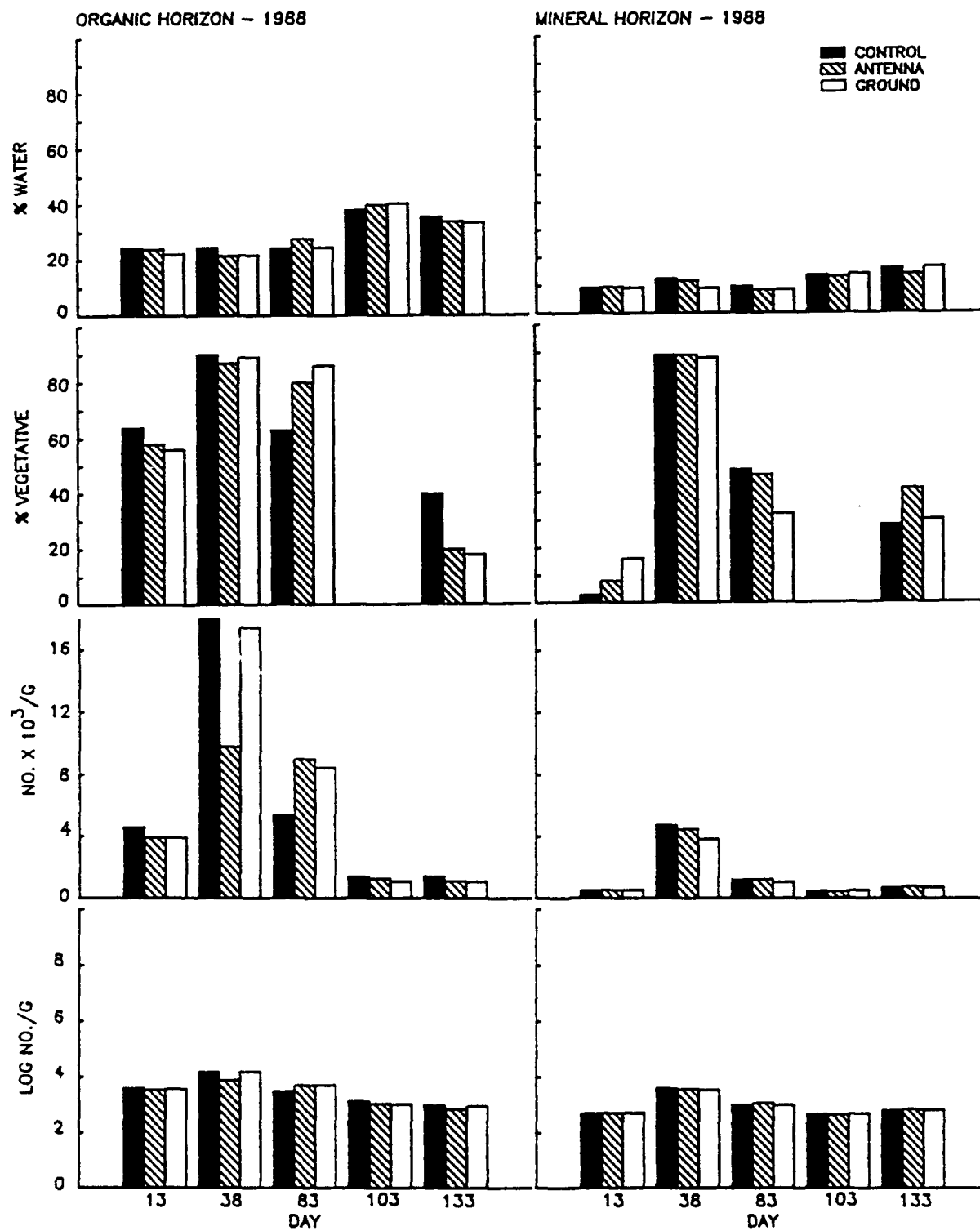


Figure 1G. Summary of previous years.

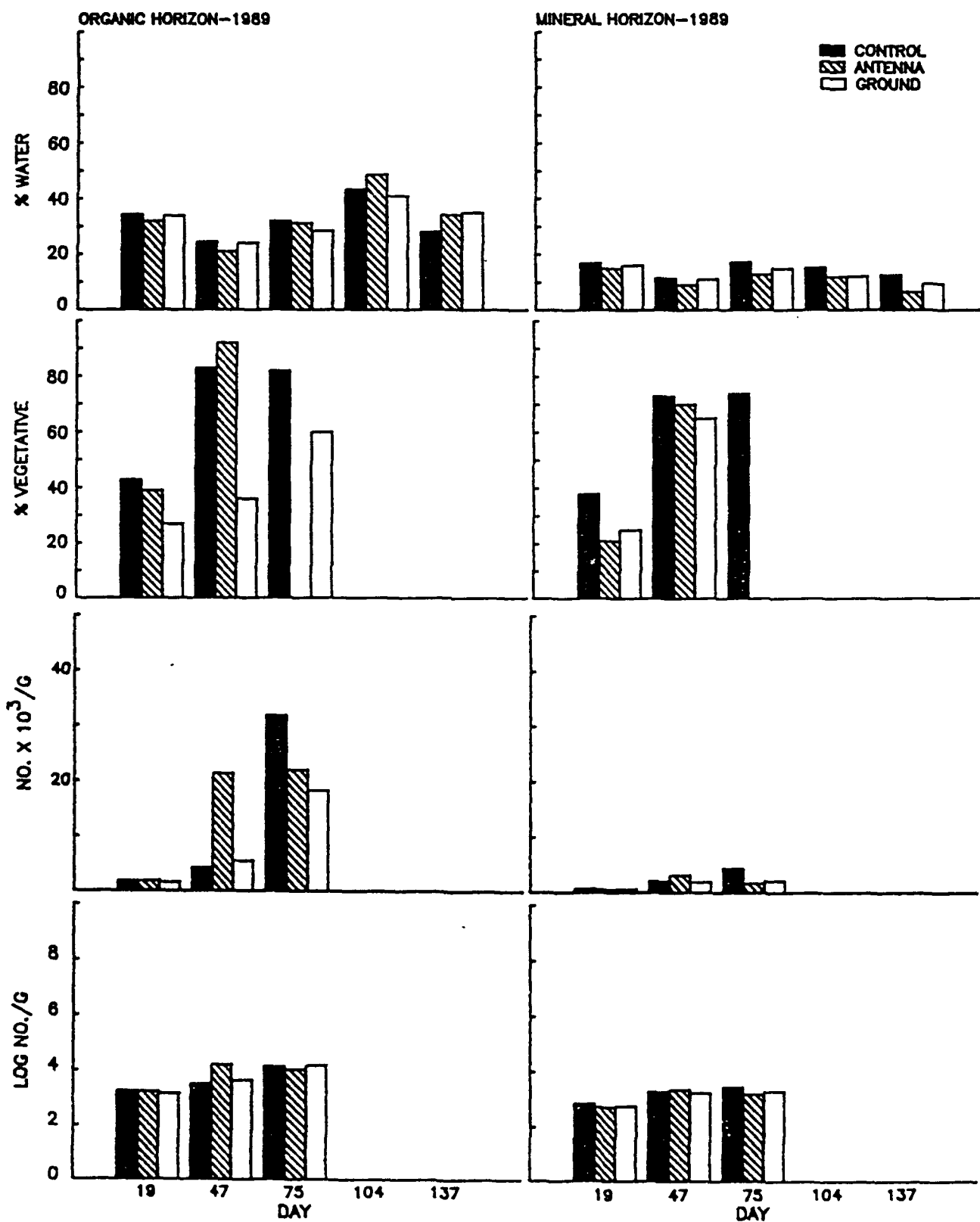


Figure 1H. Maximum average yields by year and month for all sites.

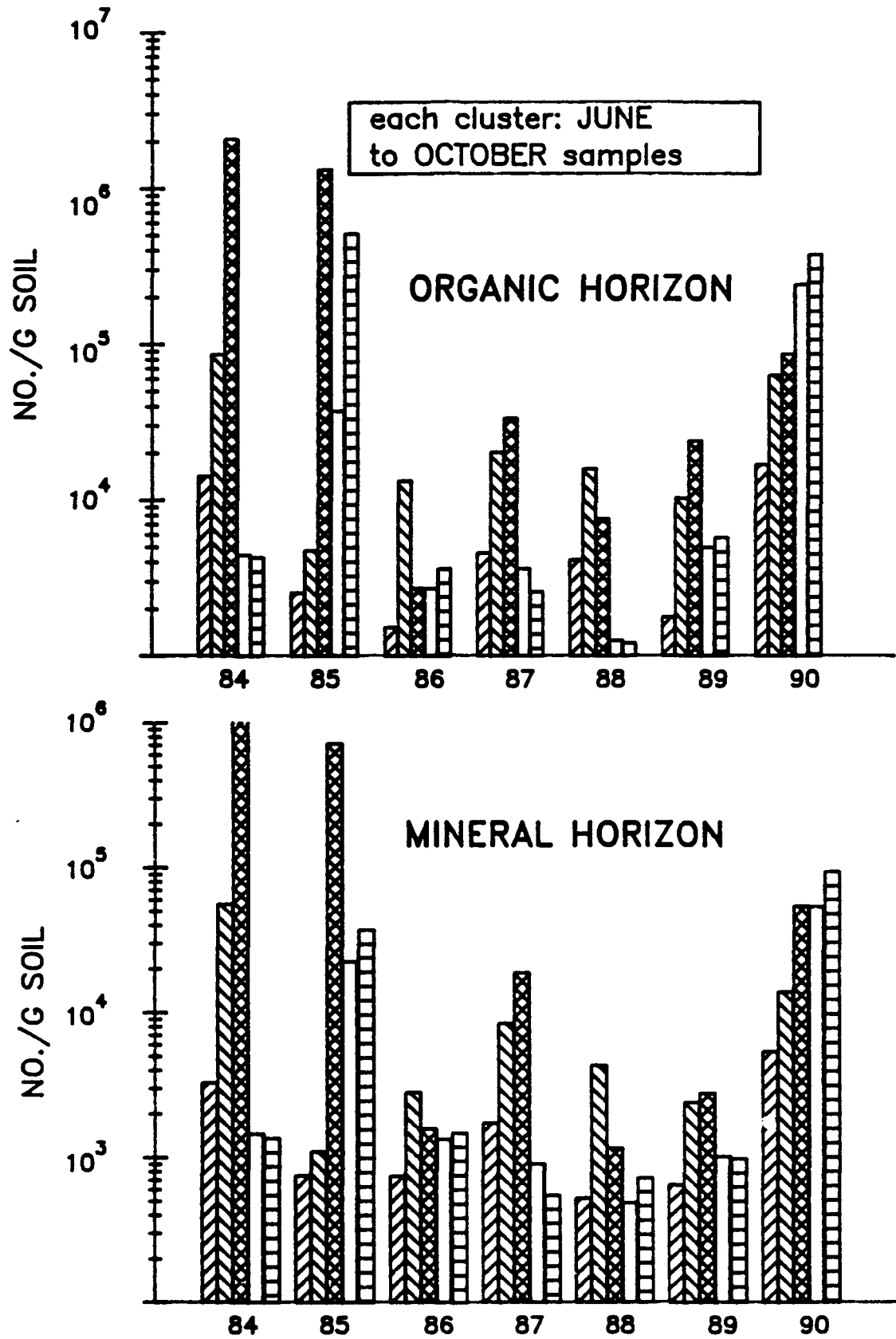


Figure 2. Moisture content of soil samples taken for counting amoebae

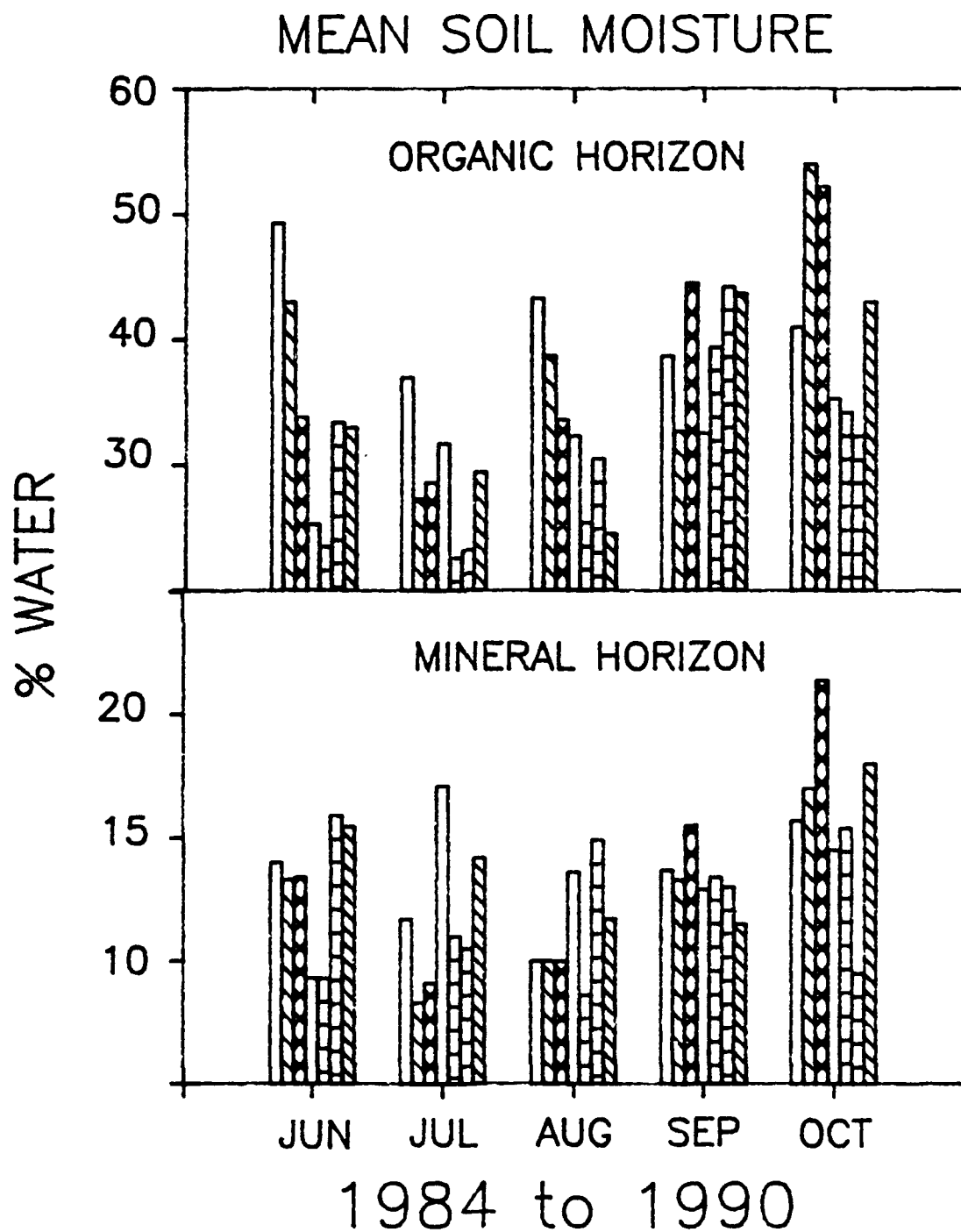


Figure 3. Annual rainfall departure from normal for 1984 & 1985 (normal rain) and for the drought years.

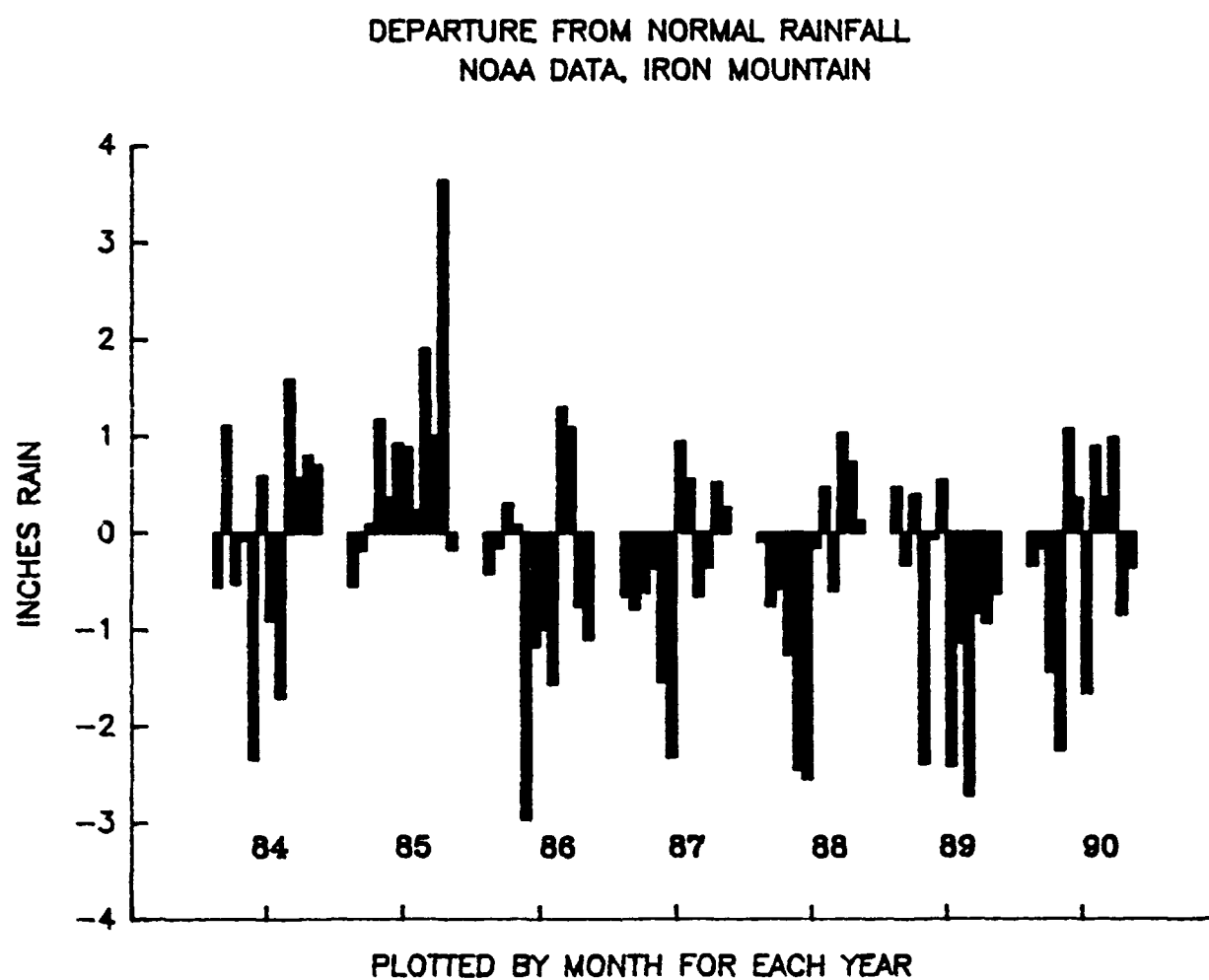


Figure 3A Annual departure from normal rainfall.

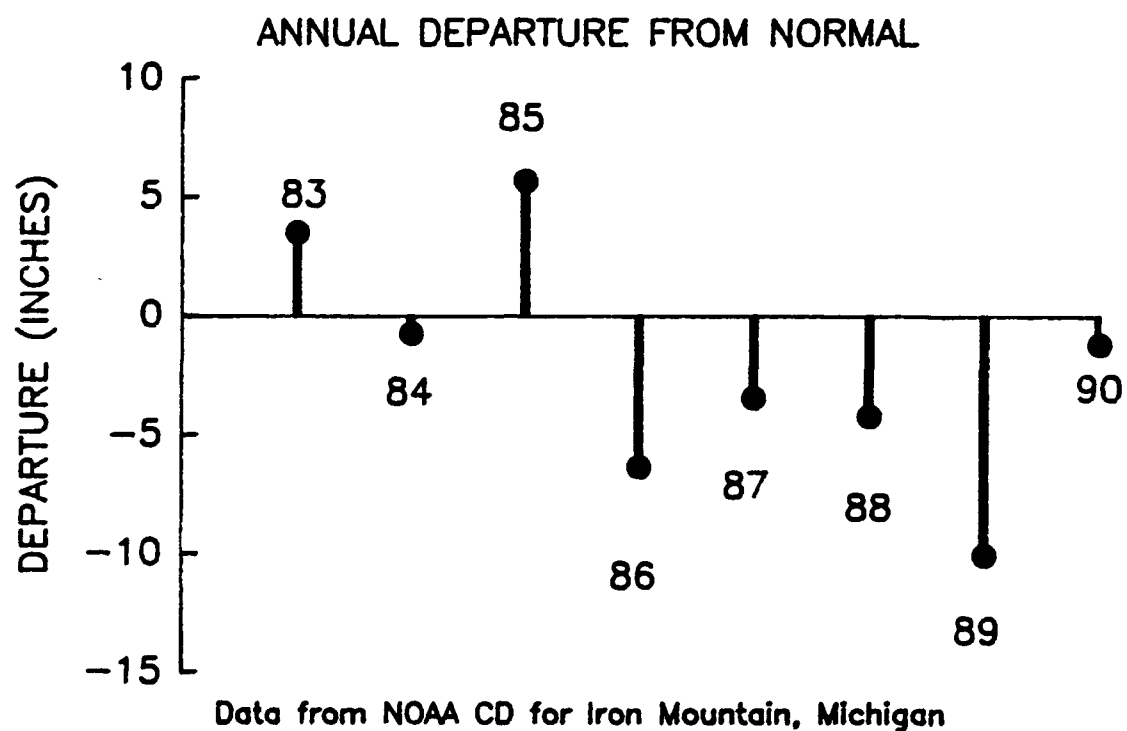


Figure 3B. Average maximum total amoebae per year.

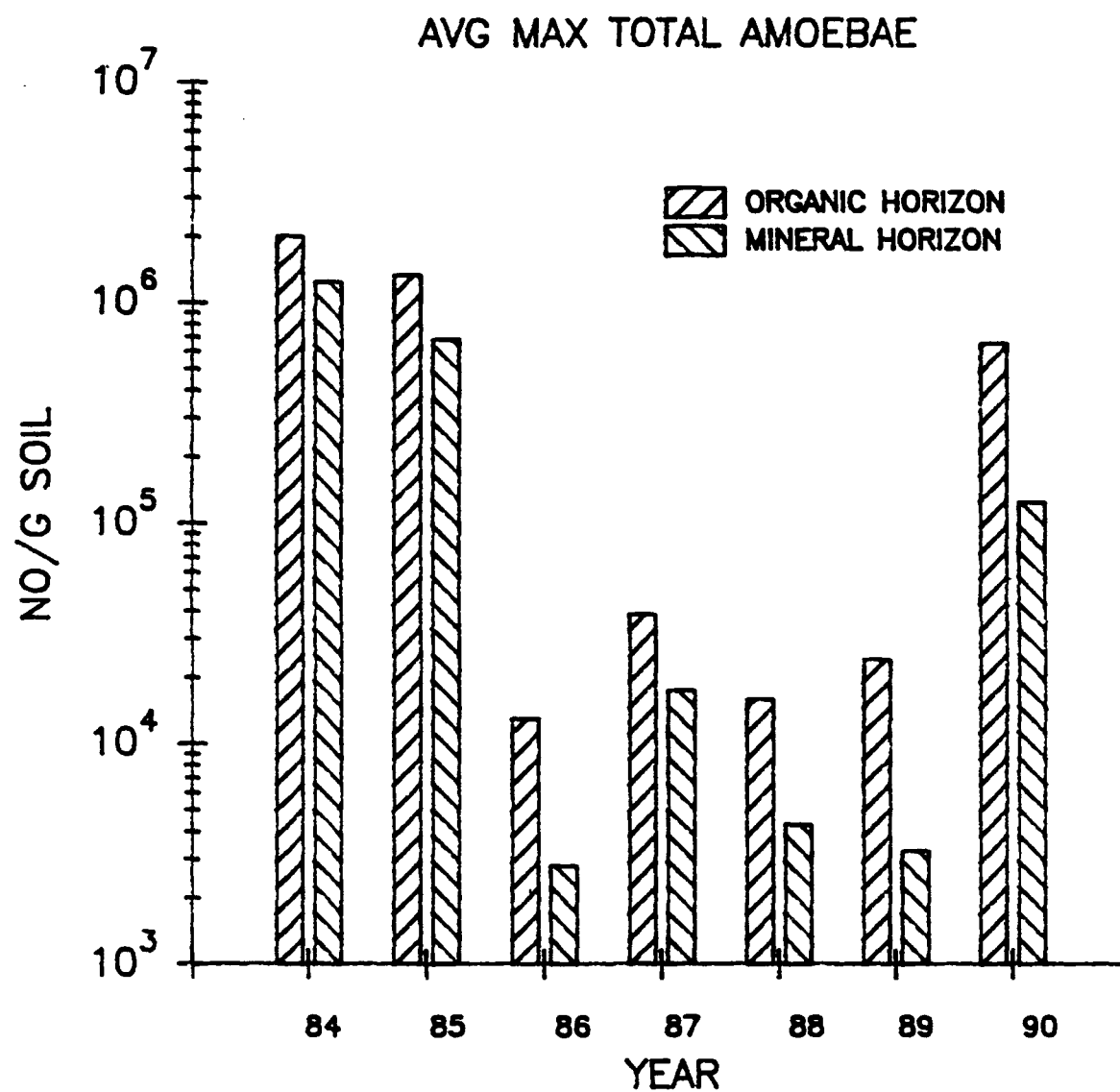


Figure 4A. Pooled temperature records showing mean daily temperatures with S.D. error bars, plotted every third day (top); 7 year summary (bottom)

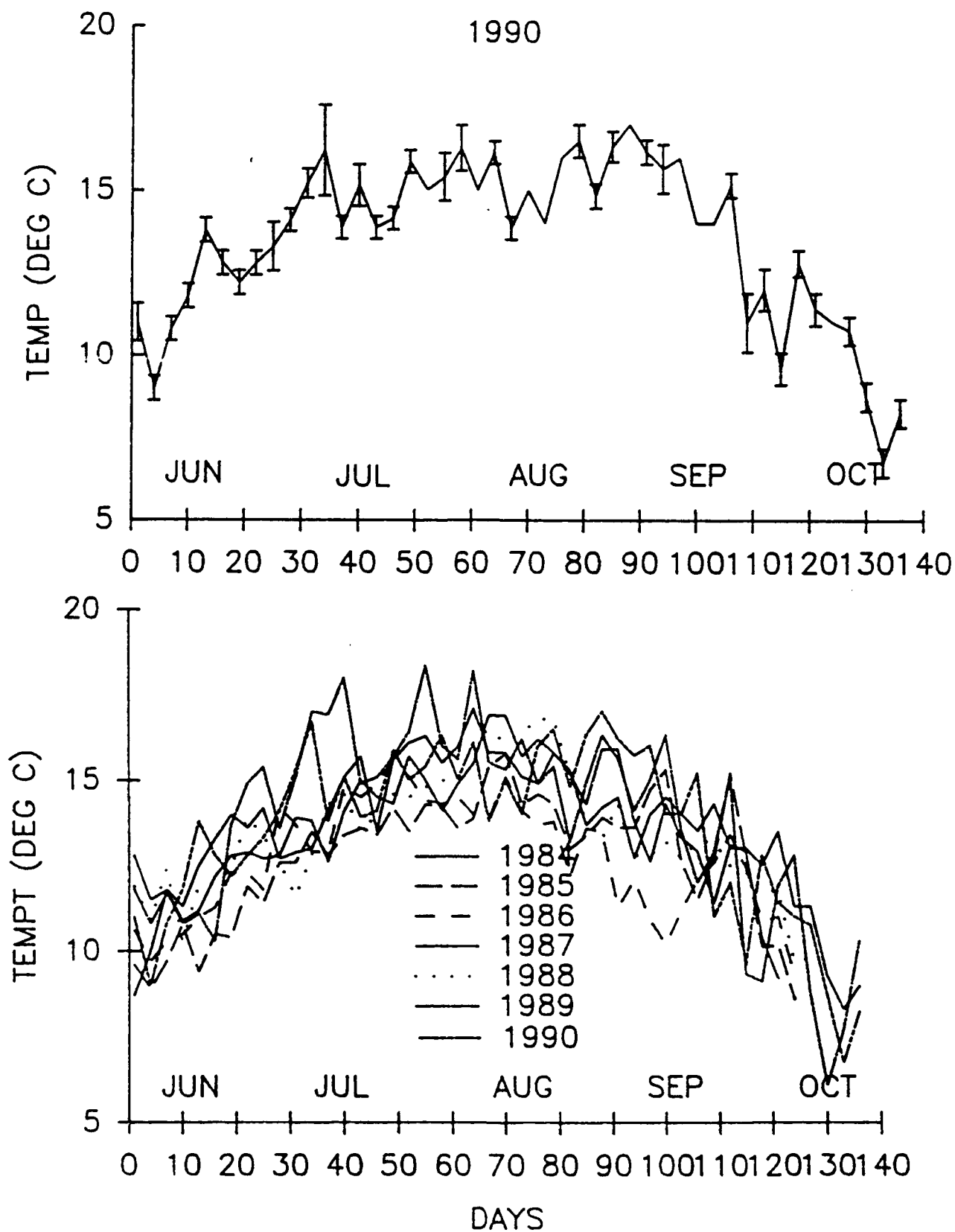




Figure 4B. Pooled temperature records showing mean daily temperatures, a comparison of IITRI temperature records and my data (top); IITRI data plotted every third day with S.D. error bars.

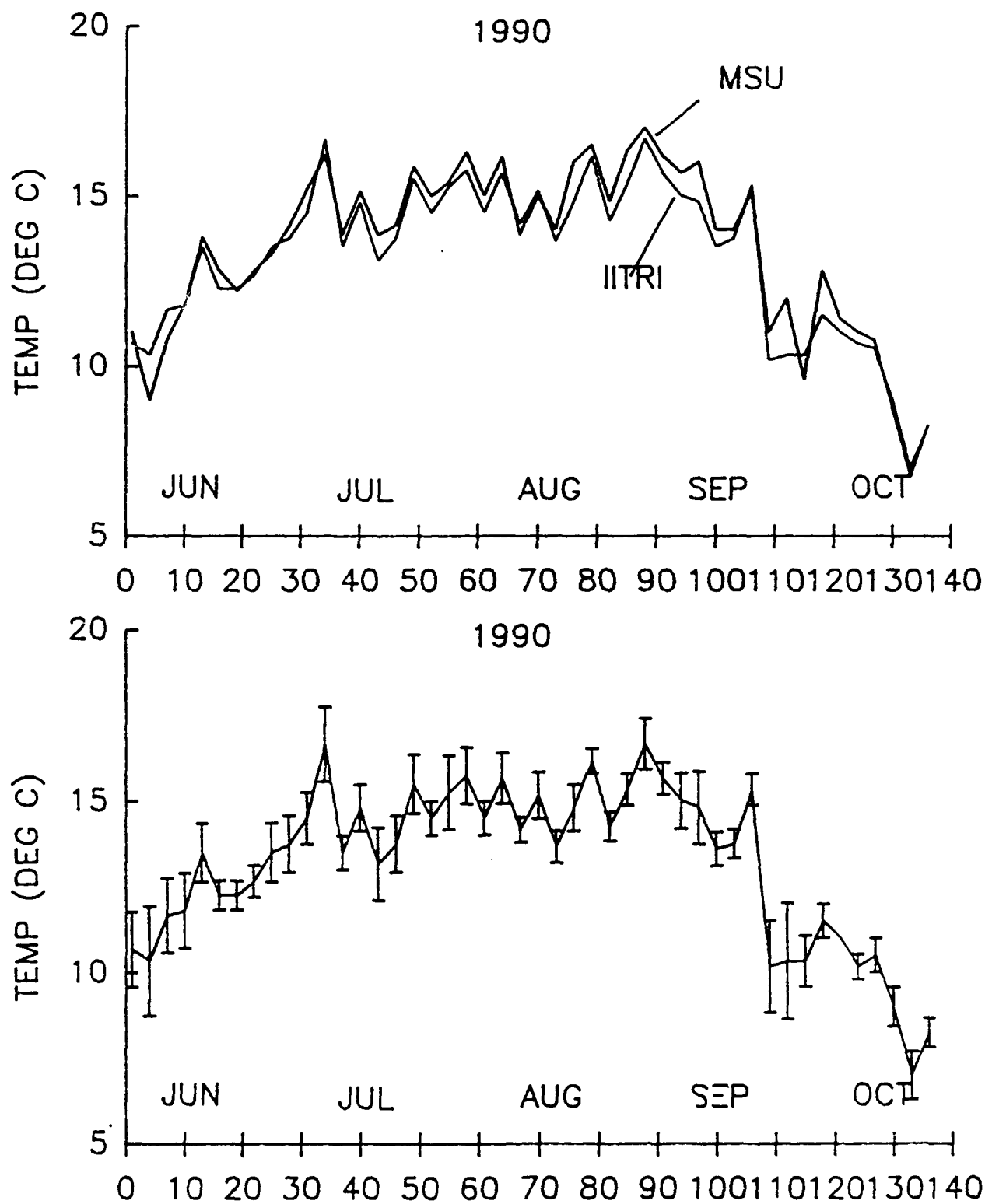


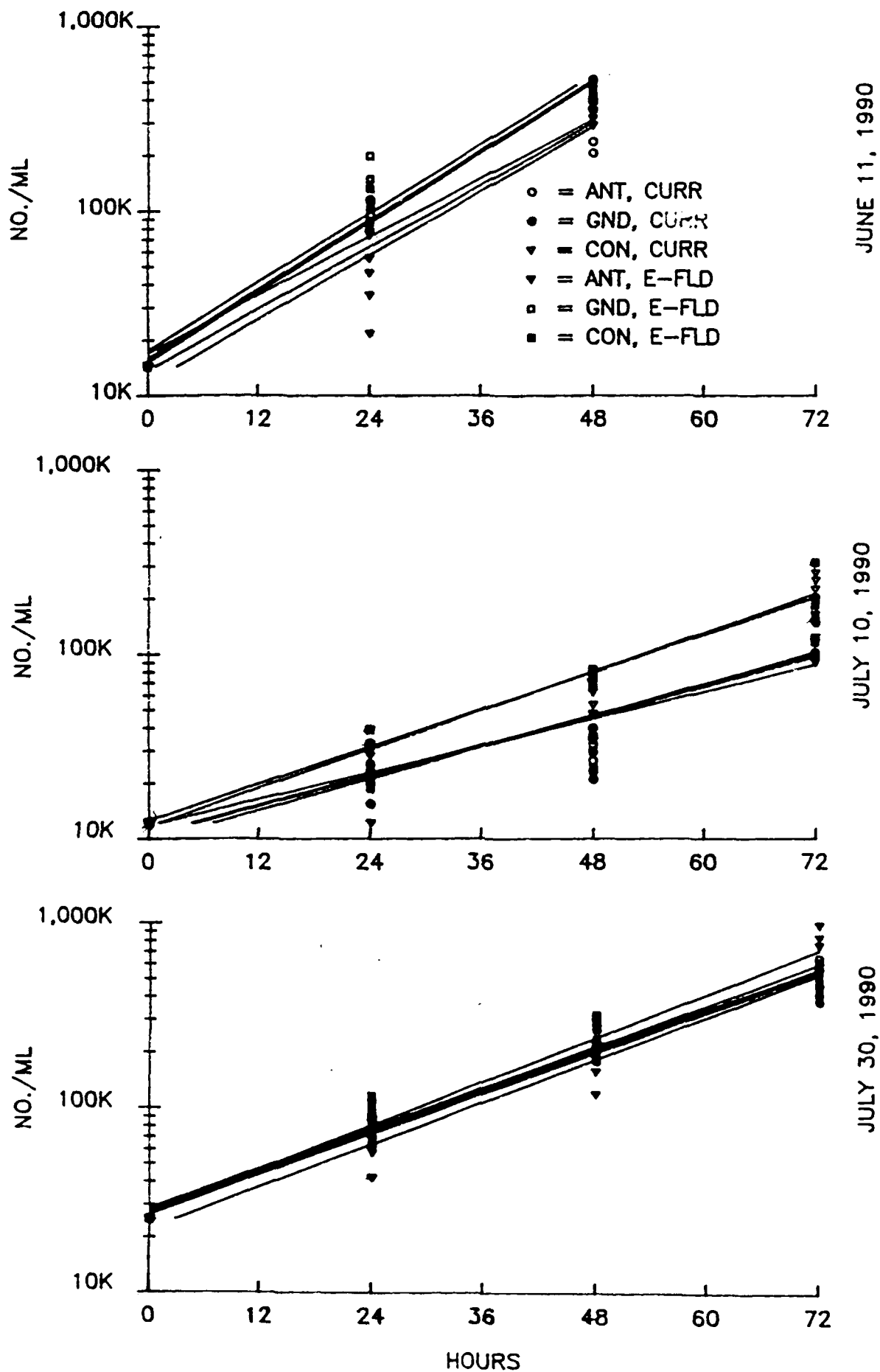
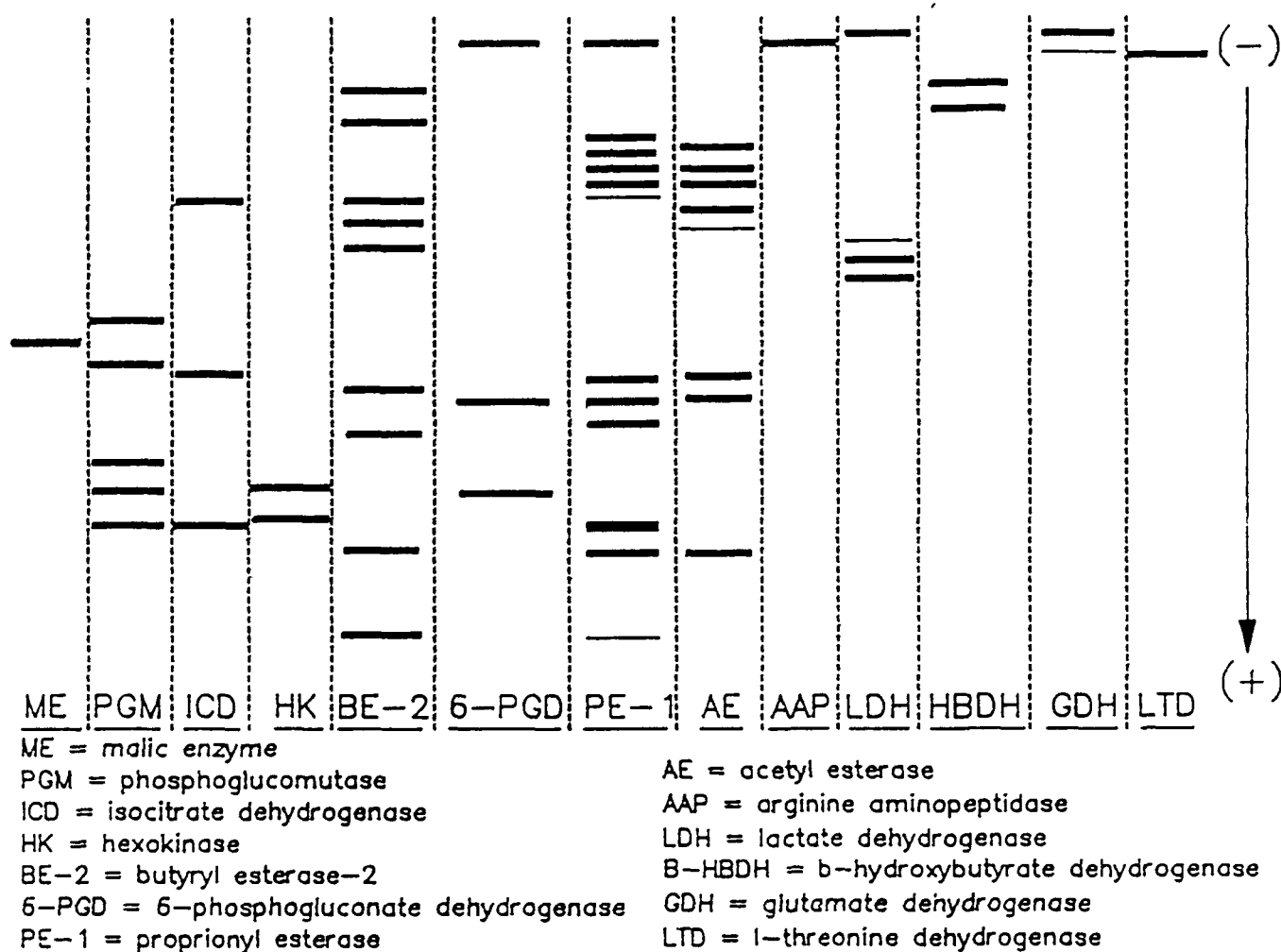
Figure 5. Growth of *Acanthamoeba polyphaga* in soil submerged cultures.

Figure 6. Isozyme patterns for *Acanthamoeba polyphaga* clone used in soil submerged cultures.



Subcontractor: Michigan State University

East Lansing, Michigan 48824

Subcontract No. E06595-88-C-004

ELF Communications System Ecological Monitoring Program

Arthropoda and Earthworms

Tasks 5.3. and 5.4.

Annual Report

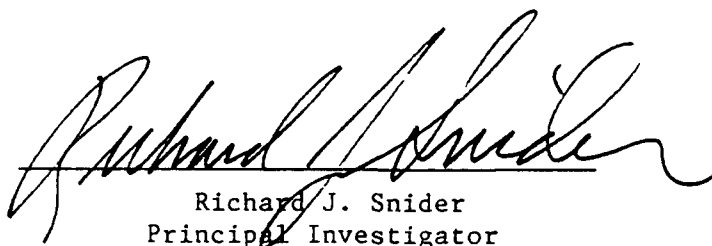
1990

Subcontractor: Michigan State University  
East Lansing, Michigan 48824


Subcontract No. E06595-88-C-004

ELF Communications System Ecological Monitoring Program  
Arthropoda and Earthworms  
Tasks 5.3. and 5.4.

Annual Report  
1990



Richard J. Snider  
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---

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Michigan State University

## TABLE OF CONTENTS

|  |    |
|--|----|
| ABSTRACT .....   | 1  |
| SUMMARY .....  | 3  |
| I. ELECTROMAGNETIC FIELDS .....                              | 9  |
| II. ENVIRONMENTAL MONITORING .....                           | 11 |
| 1. Precipitation .....                                       | 11 |
| 2. Soil and litter moisture .....                            | 11 |
| 3. Temperature .....   | 14 |
| III. SOIL AND LITTER ARTHROPODA .....                        | 17 |
| 1. Statistical approach .....                                | 17 |
| 2. Soil and litter Collembola .....                          | 18 |
| 2.1. Efficiency of soil core extraction .....                | 18 |
| 2.2. Annual mean densities .....                             | 18 |
| 2.3. Diversity .....   | 23 |
| 2.4. <i>Isotoma notabilis</i> .....                          | 24 |
| 3. Acari of litter and soil .....                            | 29 |
| 3.1. Extraction efficiency .....                             | 29 |
| 3.2. Density .....   | 30 |
| 3.3. Population structure .....                              | 34 |
| IV. SURFACE-ACTIVE ARTHROPODA .....                          | 39 |
| 1. Statistical approach .....                                | 39 |
| 2. Collembola .....  | 40 |
| 3. Acari .....   | 44 |
| 3.1. <i>Trombidium auroraense</i> .....                      | 44 |
| 3.2. <i>Abrolophus</i> sp. ....                              | 44 |
| 3.3. <i>Nanorchestes</i> sp. A .....                         | 47 |
| 4. Carabid beetles .....                                     | 50 |
| 4.1. Sex ratios .....  | 50 |
| 4.2. Fecundity .....   | 52 |
| 4.3. Developmental patterns .....                            | 54 |
| V. EARTHWORMS .....  | 63 |
| 1. Statistical approach .....                                | 63 |
| 2. Species composition and abundance .....                   | 64 |
| 3. Vertical distribution .....                               | 66 |
| 4. Cocoon weights .....                                      | 69 |
| 5. <i>Aporrectodea tuberculata</i> .....                     | 71 |
| 5.1. Choice of variables .....                               | 71 |
| 5.2. Results .....   | 77 |
| 5.3. The case of <i>turgida</i> vs. <i>tuberculata</i> ..... | 81 |
| 6. <i>Lumbricus rubellus</i> .....                           | 85 |
| 6.1. Annual population structure .....                       | 85 |
| 6.2. Reproduction .....                                      | 88 |

|  |     |
|--|-----|
| 7. Dendrobaena octaedra .....                            | 92  |
| 7.1. Parameters of reproduction and development..        | 93  |
| 8. Conclusions .....                                     | 99  |
| VI. LITTER INPUTS AND DECOMPOSITION .....                | 103 |
| 1. Litter inputs .....                                   | 103 |
| 2. Litter standing crops and turnover .....              | 103 |
| 3. Litterbags .....                                      | 107 |
| 3.1. Experimental protocol .....                         | 107 |
| 3.2. Results .....                                       | 110 |
| APPENDIX A: Electromagnetic measurements in detail ..... | 115 |

## ABSTRACT

The sampling schedules and procedures were followed in 1990: diel pit-trapping at weekly intervals, arthropod and earthworm sampling at intervals of two weeks from early May to late October. Data on arthropods collected in 1990 are not yet available, but earthworm and litter decomposition data were completed and subjected to analysis.

Annual abundances of several arthropod taxa frequenting soil and leaf litter remained correlated between sites through 1989. Diversity of collembolan communities decreased over the years to the same degree in Test and Control, but stabilized in 1989 in both sites. In most species used as indicators of potential disturbance, developmental patterns (measured by seasonal frequencies of developmental stages) were well synchronized between sites. Females of four species of carabid beetles obtained by pit-trapping were dissected; numbers of ripe eggs in their ovaries were not significantly different within a given year. An anomaly in the breeding cycle of one of these species occurred in 1988, but was observed in both sites. Activity of other trapped arthropods fluctuated synchronously in Test and Control in 1989, much as in past years.

Vertical distribution of litter-dwelling earthworms in both sites was less well related to litter moisture than in previous years; however, unusually high and constant moisture over most of the year resulted in that parameter being non-discriminant. All other species showed vertical distributions in response to moisture consistent with previous observations.

No clear evidence was found that litter- and surface-soil dwelling species were adversely affected by electromagnetic fields, but continued monitoring will be needed to pursue minor deviations observed. The dominant soil-dwelling species in the Test site appeared to have suffered reduced repro-



ductive activity not consistent with the relatively high soil moistures recorded in 1990. Future years' data will be used to validate the conclusions derived from a single, first operational year.

Litter inputs in 1990 differed neither from past years nor between sites. Turnover rate estimates for natural forest floor litter, unusually high in the Control site in 1989, returned to a value of approximately 1 year for both sites in 1990. Results of decomposition experiments (litterbags) showed that litter disappearance rates in the Test site did not differ from pre-ELF years. The litterbag study was again expanded in November of 1990 to include an Exchange series (Control litter placed in the Test site and vice versa), and will be continued until the project ends.

## SUMMARY

Sampling and extraction protocols were adhered to in 1990, from May 7 to October 22. Earthworm and arthropod populations frequenting litter and soil were sampled at intervals of two weeks; diel activity of arthropods was monitored at weekly intervals by pit-trapping. Temperature, rainfall, soil and litter moisture, and litter input and decomposition data were obtained at appropriate intervals.

Species identifications of arthropods for 1990 are as yet incomplete, but virtually all 1989 data were available for analysis. All earthworm data through 1990 were completed. Data bases on population structure of Isotoma notabilis, and on fecundity estimates for four species of carabid beetles, were brought up to date.

Results can be summarized according to three main categories:

1. Seasonal and yearly fluctuations in population abundance.

Mean annual abundance estimates for several major taxa of arthropods, including Collembola in toto, continued to remain tightly correlated between sites. Anova of annual diversity indices of the collembolan communities revealed significant site effects (Control diversity has been consistently lower than Test), but gradual decreases in diversity, as evidenced by lack of site x year interactions, have occurred in parallel in both sites.

With respect to 1990 earthworm populations, the epigeic Dendrobaena octaedra remained at its 1989 low in Test, but increased drastically in Control due to high cocoon production in the preceding year; Test site results are not entirely explainable at this time. Lumbricus rubellus experienced a significant numerical increase over all previous years, due to high cocoon production in 1989 coupled with good survival of 1990 recruits after their May emergence peak. For neither of these two species

could ELF effects be demonstrated, although minor discrepancies (such as a low proportion of clitellates among L. rubellus adults) indicate the need for continued monitoring as well as for more extensive analyses of existing data.

Among endogeics, Aporrectodea trapezoides (rare in Test, common in Control) has steadily increased over the years. Aporrectodea tuberculata in Test, and even more so A. turgida in Control, reached abundance peaks which were predicted last year based on prior years' cocoon production.

## 2. Population characteristics other than abundance per se.

a. Behavioral traits: within-year correlations between Test and Control pit-trap catches remain the major tool for assessing potential changes in activity patterns. Among Collembola, Sminthurinus henshawi, Sminthurides lepus and Orchesella hexfasciata showed significantly correlated trap catches over time, as did Sminthuridae and Entomobryidae at the family level. Much like Collembola, Nanorchestes sp. is active year-round, with consistently good correlation between sites. The same can be said of strongly seasonal taxa among mites and beetles, in which peak activity generally coincides with peak reproductive activity. Data for 1989 carabid beetles are still incomplete, but we were able to describe the breeding/developmental cycles of four species based on seasonal frequencies of female developmental categories. Gravid females were the most active, with good correlation of seasonal captures between sites.

In response to litter and soil moisture, earthworms migrate vertically between litter and A horizon (epigeics and intermediates) or between A horizon and the underlying B layers (endogeics). Colonization of litter by D. octaedra was not significantly related to litter moisture in 1990. Litter moistures were consistently high on most sampling occasions and may

have exceeded the lower threshold value for the species; above this threshold, moisture is not a discriminant factor for population distribution.

The proportion of L. rubellus in litter was again significantly related to moisture (unlike 1989); the relationship seems to be weakest in years when small immatures are scarce. Vertical distribution of A. tuberculata and A. turgida in response to A horizon moisture is, on the average, essentially equal. In Test, A. tuberculata behavior did not differ from pre-ELF years.

b. Population structure: the seasonal appearance or frequency of life stages can be documented by size measurements (Collembola), identification of discrete developmental stages (Acari), or recording of body weight and state of sexual development (earthworms).

Among arthropods chosen as indicator species, Mesostigmata A has proven of little use for project goals: not because there are site differences, but because these differences were consistent neither over years nor among stages. Asca aphidioides, on the other hand, showed good correlation between sites and years: its univoltine life cycle begins with gravid adults in the spring, and after recruitment and growth of the year's cohort during summer, ends again with high (up to 100%) proportions of females in September. In Isotoma notabilis, first instar and adult abundances, as well as their seasonal frequencies, showed significant consistency between sites.

Developmental patterns of earthworms do not lend themselves to rigorous statistical comparisons, but their documentation is essential for understanding long-term population trends. In 1990, the growth pattern of L. rubellus emerged with particular clarity due to a single high peak of recruits in May; our previous estimate of approximately 1.5 years of growth before reaching maturity was confirmed.

c. Reproductive parameters: we now have estimates of carabid fecundity for four species and four pre-ELF years (1985 through 1988). Between-site differences in the number of ripe ova carried by females have not been significant, although differences between years are likely to occur.

Mean weights of earthworm cocoons did not differ from pre-ELF years, if we take into account that the lowest weights for A. tuberculata were obtained in the driest years, all of them pre-operational. Other important parameters we examined included: annual density of new cocoons; the proportion of adults in the clitellate state; and clitellate abundance. Neither in L. rubellus nor in D. octaedra were there clear indications of adverse effects by ELF operation, although further statistical treatments are still pending. Tentatively, minor discrepancies (e.g., low proportion of clitellates among adults of L. rubellus) suggest that continued monitoring is advisable.

For A. tuberculata, we chose to use multi-year pre-ELF means of the above parameters as a measure of average species potential under a variety of conditions. Deviations from these means, summed over 12 dates per year, yielded year-specific data from which predictive equations (with soil moisture deviations as the independent variable) were derived. In spite of large confidence limits, 1990 proved to be outlying (but not 1989): neither of the three reproductive variables were as high as predicted by the species' pre-ELF performance. With caution, we supported these conclusions by comparing reproductive parameters of A. tuberculata and A. turgida, its sister species in the Control site. Overall, we believe the evidence to be strong enough to warrant not only continued monitoring, but also implementation of controlled field experiments as soon as possible. Given the long time needed for growth and maturation of A. tuberculata, we suggest that two years of on-line ELF operation may be insufficient to reach definite

conclusions.

3. System-level parameters.

Litter inputs in 1990 were consistent between sites and all years. Turnover time estimates for natural litter have returned to approximately 1 year in both sites, after a discrepancy was observed in 1989 in the Control site. Breakdown of litter in large-mesh bags, however, has remained discrepant between sites, being slower in Control than in Test. Pre-ELF decomposition rates in Test, however, did not differ from those obtained in 1990. We tentatively explained the phenomenon by drastic yearly fluctuations of D. octaedra populations in Control during the first fall-winter-spring months of litter decomposition in the field.

We have again expanded the litterbag study to include a series of "Exchange bags" placed in the field in November of 1990 (Test litter in Control and vice versa). We will continue to obtain first-year decomposition estimates until the project ends.

# I. ELECTROMAGNETIC FIELDS

Data for the past three years provided by IITRI (D.P. Haradem and J.R. Gauger) are shown in Tables 1 and 2 so that between-site comparisons can be made. Two measurement points in the Control site, and six in Test, have routinely been revisited by IITRI engineers. Measurements from 1989 and 1990 clearly show that 76 Hz exposure criteria ( $\text{Test} \geq 100 \times \text{Control}$ ) are well met. For complete information including earlier years and 60 Hz measurements, consult Appendix A.

Table 1. 76 Hz longitudinal electric field intensities (mV/m) in Test and Control soils, 1988-1990.

|         |   | 1988          |               | 1989          | 1990          |
|---------|---|---------------|---------------|---------------|---------------|
|         |   | NS<br>75 amps | EW<br>75 amps | B<br>150 amps | B<br>150 amps |
| Control | 1 | 0.093         | 0.027         | 0.22          | 0.21          |
|         | 2 | 0.170         | 0.021         | 0.38          | 0.29          |
| Test    | 1 | 27            | 2.6           | 58            | 55            |
|         | 2 | 26            | 3.0           | 60            | 53            |
|         | 3 | 27            | 2.7           | 49            | 56            |
|         | 4 | 29            | 2.6           | 62            | 50            |
|         | 5 | 27            | 2.8           | 52            | 59            |
|         | 6 | 27            | 2.4           | 49            | 49            |

NS = North-south antenna

EW = East-west antenna

B = NS + EW antennas, standard phasing

The Naval Radio Transmitter Facility - Republic (NRTF-Republic) operated intermittently on weekdays only in 1988 and early 1989 with single antenna configuration and reduced antenna currents (Table 3). Operation with 150 ampere antenna currents began on 14 May 1989, with intermittent transmission during weekday workhours and continuous transmission overnight and on weekends until 6 October 1989. The NRTF-Republic began continuous operation with

both antennas at 150 amperes and 76 Hz on October 7, 1989, and continued in that mode throughout 1990, with the exception of off times for scheduled maintenance.

Table 2. 76 Hz magnetic flux densities (mG) in Test and Control soils, 1988 - 1990.

|         |   | 1988    |         | 1989     | 1990     |
|---------|---|---------|---------|----------|----------|
|         |   | NS      | EW      | B        | B        |
|         |   | 75 amps | 75 amps | 150 amps | 150 amps |
| Control | 1 | 0.008   | 0.003   | 0.019    | 0.018    |
|         | 2 | 0.007   | 0.002   | 0.017    | 0.017    |
| Test    | 1 | 0.88    | 0.012   | 1.84     | 1.81     |
|         | 2 | 1.11    | 0.012   | 2.30     | 2.20     |
|         | 3 | 0.89    | 0.012   | 1.81     | 1.80     |
|         | 4 | 1.08    | 0.012   | 2.30     | 2.20     |
|         | 5 | 1.03    | 0.012   | 2.20     | 2.10     |
|         | 6 | 0.90    | 0.012   | 1.88     | 1.89     |

NS = North-south antenna

EW = East-west antenna

B = NS + EW antennas, standard phasing

Table 3. NRTF-Republic operations summary, 1988-1990.

| Time period      | Operating Mode                    | Antenna configuration    | Antenna Frequ.(Hz) | Antenna curr.(amps) |
|------------------|-----------------------------------|--------------------------|--------------------|---------------------|
| 1/1/88-5/7/88    | intermittent weekday              | single antenna           | 44 or 76           | .15                 |
| 6/7/88-3/5/89    | intermittent weekday              | single                   | 44 or 76           | 75                  |
| 4/5/89-13/5/89   | intermittent                      | single                   | 44 or 76           | 150                 |
| 14/5/89-6/10/89  | weekdays                          | intermittent 8:am - 4:pm | 44 or 76           | 150                 |
|                  | weekdays                          | continuous 4:pm - 8:am   | 76                 | 150                 |
|                  | weekends                          | continuous all day       | 76                 | 150                 |
| 7/10/89-31/12/90 | continuous except for maintenance | both                     | 76                 | 150                 |



## II. ENVIRONMENTAL MONITORING

### 1. Precipitation

Site-specific monthly precipitation totals for 1990 are shown in Table 4. Rains were ample during the first and last two months of the season, somewhat deficient in July and August. Weekly totals (Fig. 1) illustrate that major rainfall events occurred at approximate intervals of two to three weeks. Compared to most previous years, precipitation was relatively evenly distributed over the year.

Table 4. Monthly precipitation totals in Test and Control sites, 1990, and 30-year means for the area at large (Crystal Falls Weather Station).

|                 | May  | June  | July | Aug  | Sept  | Oct  | Totals |
|-----------------|------|-------|------|------|-------|------|--------|
| Control         | 86.6 | 92.1  | 59.0 | 42.2 | 119.1 | 77.2 | 476.2  |
| Test            | 88.9 | 101.5 | 51.4 | 77.0 | 81.9  | 76.0 | 476.7  |
| 30-yr $\bar{x}$ | 81.0 | 105.4 | 91.4 | 98.5 | 84.6  | 52.8 | 513.7  |

### 2. Soil and litter moisture

Much as in previous years, fluctuations in bi-weekly litter moisture estimates were clearly correlated between sites (Fig. 2). A horizon moisture, typically slightly higher in Control than in Test, never fell below 20% in either site (Fig. 2). Both A and B horizons were more stable with respect to seasonal moisture variations than in many previous years.

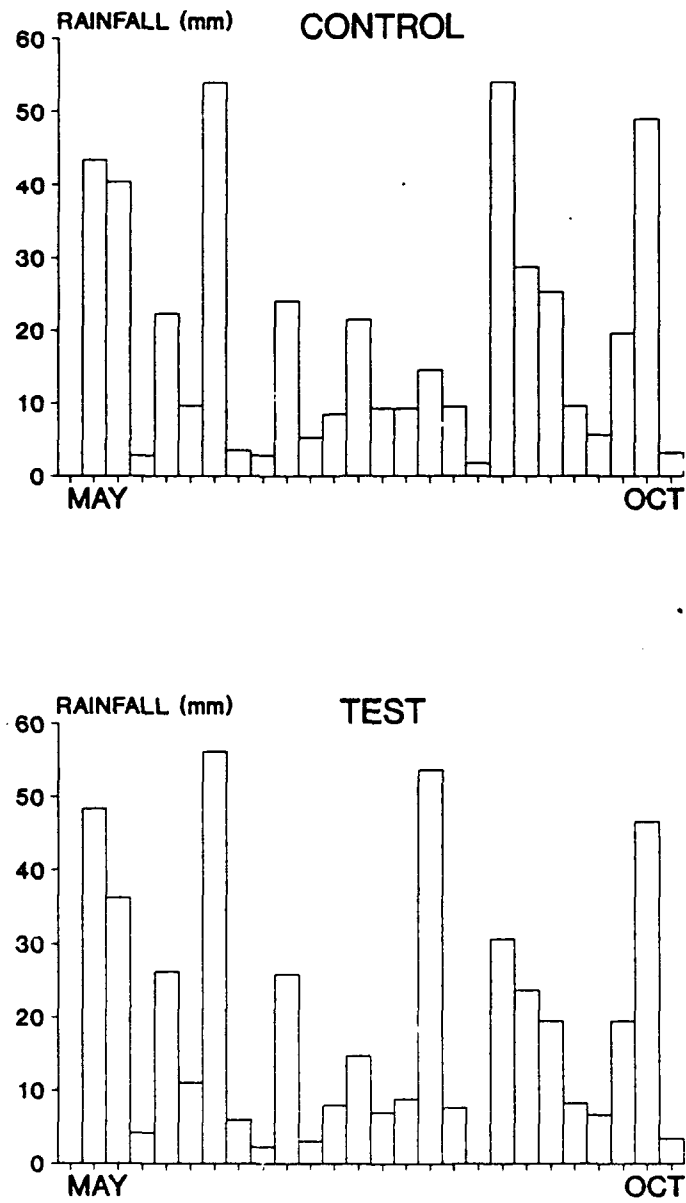


Fig. 1. Weekly precipitation totals in Test and Control, 1990.

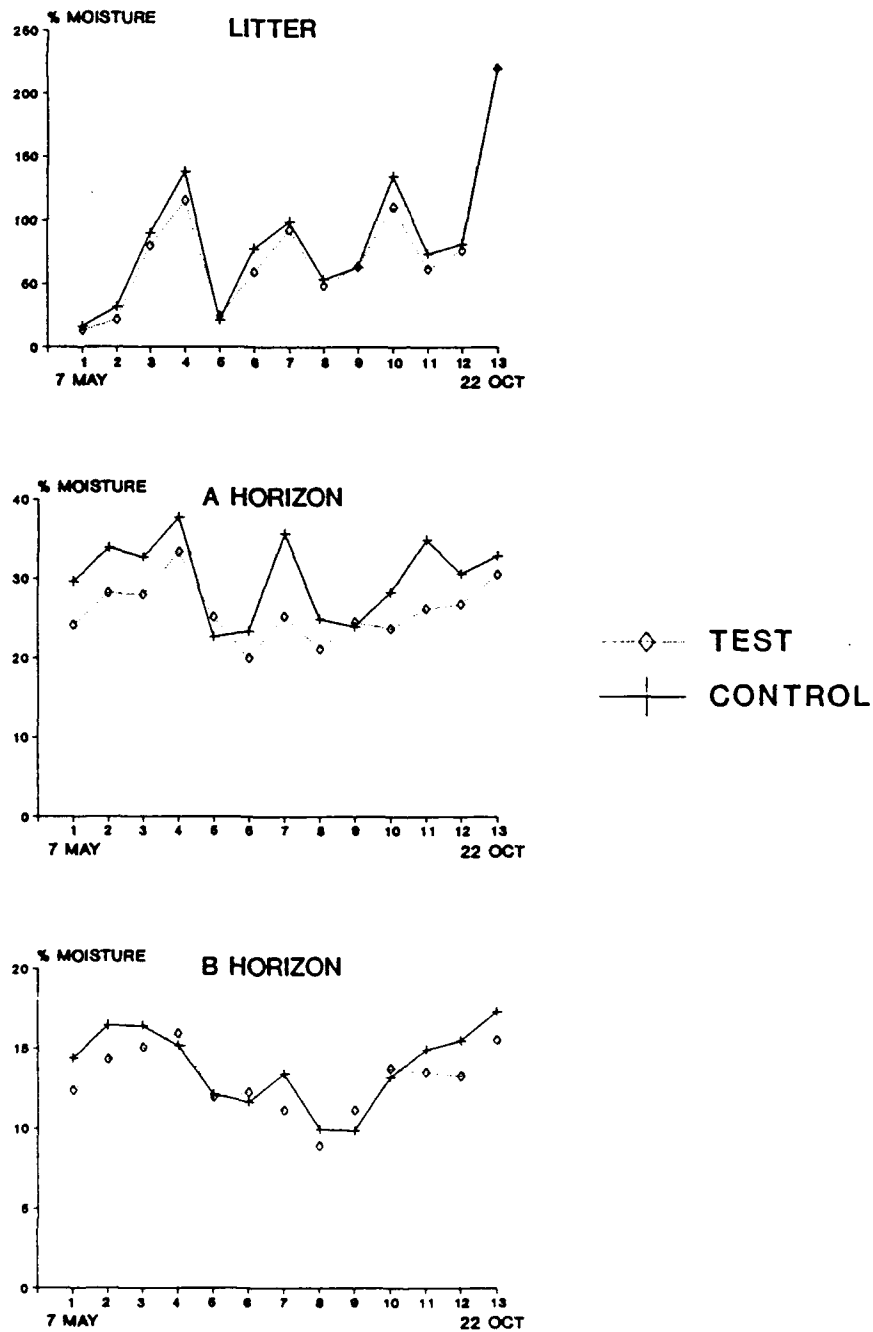


Fig. 2. Litter and soil moisture (% of dry weight) on each biweekly sampling occasion in Test and Control, 1990.

### 3. Temperature

Air and soil temperatures logged (at 1 hr and 2 hr intervals respectively) by Omnidata equipment are available for use in faunal analyses where appropriate. We should point out that air, soil surface and soil temperatures have proven essentially equal in Test and Control (validated by periodic YSI Telethermometer readings).

We chose to present A horizon temperatures as an example of between-year variability. Weekly mean temperatures at 5 cm depth are listed in Table 5, together with biweekly precipitation totals stemming from the two weeks prior to each sampling occasion. As opposed to 1987 and 1988, for instance, humus temperatures in 1990 were generally cooler, rarely exceeding 16°C. A brief survey of rainfall data (Table 5) helps to reiterate earlier comments regarding the extent and seasonal distribution of rains in 1990 versus previous years.

Table 5. Average weekly temperature at 5 cm depth and total biweekly precipitation in the Test site, 1985 - 1990 (no continuous recordings are available for 1984 temperatures); week 1 begins on May 1.

| Week | 1985 |       | 1986 |      | 1987 |       | 1988 |       | 1989 |      | 1990 |      |
|------|------|-------|------|------|------|-------|------|-------|------|------|------|------|
|      | °C   | rain  | °C   | rain | °C   | rain  | °C   | rain  | °C   | rain | °C   | rain |
| 1    | 9.6  | -     | 9.9  | -    | 8.8  | -     | 9.4  | -     | 5.2  | -    | 8.0  | -    |
| 2    | 12.8 |       | 11.0 |      | 11.3 |       | 9.7  |       | 7.3  |      | 6.7  |      |
| 3    | 11.3 | 17.2  | 10.8 | 1.0  | 10.6 | 42.4  | 10.5 | 14.4  | 11.7 | 12.4 | 8.2  | 84.7 |
| 4    | 11.5 |       | 11.8 |      | 10.9 |       | 11.7 |       | 12.1 |      | 10.2 |      |
| 5    | 10.9 | 56.3  | 12.8 | 0.0  | 15.1 | 65.7  | 13.9 | 14.8  | 11.4 | 60.4 | 10.6 | 30.4 |
| 6    | 12.3 |       | 11.6 |      | 13.4 |       | 13.4 |       | 11.2 |      | 11.3 |      |
| 7    | 12.0 | 28.3  | 12.0 | 18.8 | 16.4 | 44.0  | 14.4 | 17.2  | 10.9 | 99.2 | 13.8 | 67.2 |
| 8    | 13.0 |       | 13.3 |      | 16.8 |       | 15.8 |       | 14.7 |      | 13.0 |      |
| 9    | 15.0 | 9.7   | 14.4 | 33.4 | 14.6 | 10.9  | 13.3 | 11.4  | 14.7 | 39.3 | 15.1 | 8.1  |
| 10   | 15.6 |       | 16.0 |      | 16.3 |       | 16.7 |       | 16.5 |      | 15.3 |      |
| 11   | 15.5 | 26.6  | 14.7 | 24.2 | 16.3 | 128.5 | 15.9 | 41.2  | 15.2 | 13.0 | 14.0 | 28.8 |
| 12   | 15.7 |       | 17.6 |      | 18.6 |       | 16.6 |       | 15.6 |      | 15.2 |      |
| 13   | 16.1 | 22.0  | 17.4 | 21.9 | 18.1 | 36.0  | 17.2 | 7.8   | 16.3 | 25.5 | 16.1 | 22.6 |
| 14   | 16.0 |       | 15.8 |      | 17.3 |       | 18.4 |       | 17.2 |      | 15.2 |      |
| 15   | 16.7 | 98.7  | 15.3 | 36.6 | 17.1 | 53.4  | 18.1 | 128.3 | 15.2 | 63.6 | 12.8 | 15.8 |
| 16   | 15.3 |       | 15.7 |      | 17.5 |       | 17.8 |       | 14.7 |      | 15.1 |      |
| 17   | 14.6 | 36.1  | 14.1 | 32.6 | 14.7 | 32.8  | 15.4 | 61.2  | 14.8 | 10.7 | 15.6 | 61.2 |
| 18   | 14.9 |       | 13.6 |      | 13.7 |       | 14.6 |       | 14.6 |      | 15.6 |      |
| 19   | 16.2 | 65.5  | 12.1 | 26.8 | 15.0 | 5.1   | 12.8 | 30.8  | 14.9 | 68.6 | 15.1 | 30.7 |
| 20   | 12.4 |       | 10.4 |      | 14.0 |       | 13.3 |       | 11.9 |      | 13.2 |      |
| 21   | 14.7 | 33.9  | 12.1 | 67.4 | 13.0 | 54.0  | 13.4 | 65.9  | 12.7 | 2.3  | 10.8 | 43.0 |
| 22   | 10.4 |       | 14.0 |      | 12.7 |       | 12.1 |       | 10.4 |      | 11.2 |      |
| 23   | 9.8  | 115.8 | 10.8 | 22.3 | 9.3  | 17.0  | 9.1  | 17.3  | 7.8  | 13.8 | 9.9  | 14.8 |
| 24   | 9.3  |       | 7.8  |      | 7.6  |       | 7.8  |       | 8.3  |      | 7.2  |      |
| 25   | 8.7  | 20.0  | 7.6  | 74.0 | 7.6  | 31.4  | 7.6  | 51.7  | 5.7  | 24.2 | 7.1  | 66.0 |



### III. SOIL AND LITTER ARTHROPODA

Specimens obtained in 1989 have been identified, and data are presented in the following sections. Species identifications for the 1990 season are as yet incomplete.

#### 1. Statistical approach

Lacking 1990 data at this time, we chose to treat 1989, tentatively, as a pre-operational year, with reservations as discussed below.

Correlations between sites are used for within-year as well between-year testing of, for instance, abundance fluctuations of arthropods (seasonal and annual means respectively). For yearly comparisons, potential outliers (1989) are tested by means of their position with respect to the confidence limits of correlation coefficients. We may summarily add here that none were detected.

Factorial analysis of variance is used to test population parameters for which we have replication (e.g., mean annual diversity indices based on 12 or 13 dates per year). Anova without replication, using highest-level interactions as error term, is the main tool for testing seasonal frequencies of developmental stages of a given taxon. In both cases, interactions involving sites and dates are of the greatest interest. Temperatures, which are essentially equal in Test and Control, are the main driving factor for developmental rates of arthropods. Lack of synchronicity (significant site x year or site x date interactions) would point out potential discrepancies requiring further statistical or experimental exploration.

## 2. Soil and litter Collembola

### 2.1. Efficiency of soil core extraction

Sugar-floatation of soil cores after heat-extraction was begun in 1986. Data through 1989 are summarized in Table 6.

Heat extraction is relatively efficient for Sminthuridae and Neelidae, less so for Isotomidae and Entomobryidae, and very inefficient for Hypogastruridae and Onychiuridae. Percent extracted in a given family can be quite variable from year to year, usually due to highly aggregated species of which very large numbers are obtained from only a few samples per year.

Occasionally, species-specific differences emerge within a given family: among Isotomidae, for instance, Isotoma notabilis is extracted well by heat, while the subdominant Isotomiella minor is not well represented in Tullgren samples (Table 6). Because these data are relatively variable between years, we have not attempted to "correct" 1984 and 1985 density estimates for any of the taxa frequenting Test and Control soils.

### 2.2. Annual mean densities

In Table 7, we present 1989 abundance estimates for all species inhabiting leaf litter and/or soil, allowing comparison with earlier years through 1984.

In no way did 1989 appear to be unusual. Indeed, correlations between sites remain significant ( $r \geq 0.92$ ,  $P \leq 0.01$ ) for several taxa: Isotoma notabilis, Willemia intermedia, and Tullbergia granulata (for the dominant onychiurid T. mala,  $r = 0.81$ ,  $P < 0.05$ ); as well as for overall collembolan abundance ( $r = 0.99$ ,  $P < 0.001$ ). In general, year-to-year density fluctuations have thus occurred in parallel in Test and Control.



Table 6. Efficiency of heat extraction for selected taxa of Collembola, in percent of total numbers obtained by heat extraction + sugar floatation. Only the most numerous species are listed.

|                               | T E S T |      |       |       | C O N T R O L |      |       |       |
|-------------------------------|---------|------|-------|-------|---------------|------|-------|-------|
|                               | 1986    | 1987 | 1988  | 1989  | 1986          | 1987 | 1988  | 1989  |
| <u>Sminthurinus henshawi</u>  | 96.0    | 92.9 | 83.3  | 97.2  | 100.0         | 90.6 | 100.0 | 100.0 |
| Total Sminthuridae            | 88.9    | 89.0 | 85.9  | 98.4  | 100.0         | 93.8 | 98.6  | 98.4  |
| Total Neelidae                | 100.0   | 95.2 | 100.0 | 100.0 | 100.0         | 98.1 | 100.0 | 96.4  |
| <u>Isotoma notabilis</u>      | 92.4    | 90.4 | 90.7  | 84.5  | 94.2          | 87.5 | 90.2  | 90.1  |
| <u>Isotomiella minor</u>      | 43.8    | 44.5 | 30.3  | 34.3  | 50.7          | 28.6 | 22.9  | 48.3  |
| Total Isotomidae              | 77.0    | 78.3 | 80.3  | 69.5  | 84.8          | 71.3 | 68.9  | 74.0  |
| <u>Tomocerus flavescens</u>   | 76.5    | 59.7 | 72.6  | 60.5  | -             | -    | -     | -     |
| <u>Orchesella hexfasciata</u> | 82.0    | 75.0 | 73.7  | 100.0 | -             | -    | -     | -     |
| <u>Pseudosinella violenta</u> | 58.8    | 40.1 | 63.5  | 35.7  | -             | -    | -     | -     |
| Total Entomobryidae           | 67.7    | 58.0 | 72.0  | 56.7  | 79.5          | 78.0 | 93.5  | 91.7  |
| <u>Willemia intermedia</u>    | 81.7    | 21.8 | 9.4   | 33.3  | 70.0          | 7.2  | 22.1  | 24.6  |
| <u>W. similis</u>             | 57.1    | 38.4 | 18.2  | 7.5   | 77.8          | 20.3 | 15.8  | 34.4  |
| Total Hypogastruridae         | 64.2    | 31.7 | 19.7  | 20.7  | 59.3          | 19.1 | 16.4  | 33.2  |
| <u>Tullbergia mala</u>        | 27.8    | 25.2 | 15.0  | 11.0  | 23.4          | 11.9 | 7.3   | 10.0  |
| <u>T. granulata</u>           | 29.2    | 19.8 | 20.4  | 11.0  | 28.5          | 12.1 | 7.5   | 19.7  |
| <u>T. iowensis</u>            | 54.7    | 26.4 | 17.9  | 19.1  | 33.0          | 4.7  | 8.3   | 11.6  |
| <u>T. clavata</u>             | 17.6    | 14.9 | 10.4  | 8.5   | 14.2          | 21.7 | 3.9   | 20.9  |
| Total Onychiuridae            | 31.6    | 24.0 | 18.0  | 12.8  | 24.5          | 12.2 | 7.3   | 12.6  |

Table 7. Mean annual abundance /m<sup>2</sup> (litter + soil estimates summed) of Collembola in Test and Control sites, 1984-1989. Note: estimates for 1984 and 1985 not corrected for extraction efficiency.

|                           | 1984 |      | 1985 |      | 1986 |      | 1987 |      | 1988 |      | 1989 |      |
|---------------------------|------|------|------|------|------|------|------|------|------|------|------|------|
|                           | T    | C    | T    | C    | T    | C    | T    | C    | T    | C    | T    | C    |
| <u>S. henshawi</u>        | 153  | 186  | 259  | 301  | 224  | 357  | 198  | 321  | 356  | 325  | 180  | 201  |
| <u>S. lepus</u>           | 8    | 1    | 18   | 8    | 13   | 9    | 54   | 27   | 40   | 23   | 39   | 18   |
| <u>S. macgillivrayi</u>   | 8    | 1    | 28   | 2    | 12   | 4    | 8    | 10   | 10   | 3    | 37   | 36   |
| <u>A. amarus</u>          | 31   | 20   | 22   | 25   | 12   | 5    | 72   | 4    | 6    | 35   | 3    | 11   |
| <u>A. benitus</u>         | 68   | 23   | 146  | 146  | 34   | 58   | 40   | 0.2  | 16   | 1    | 22   | 16   |
| <u>A. caecus</u>          | -    | -    | -    | -    | 0.1  | 35   | 42   | 35   | 17   | 4    | 24   | 27   |
| <u>D. aurata</u>          | -    | 16   | -    | 13   | -    | 9    | 4    | 19   | 4    | 8    | -    | 6    |
| <u>D. marmorata</u>       | -    | -    | -    | 0.2  | -    | 1    | -    | 55   | 4    | 1    | 0.1  | 1    |
| <u>B. russata</u>         | -    | 0.1  | -    | -    | 4    | -    | -    | -    | -    | -    | -    | 4    |
| <u>S. intermedius</u>     | -    | -    | -    | -    | -    | 12   | -    | -    | -    | -    | -    | -    |
| <u>B. atra</u>            | -    | -    | -    | -    | -    | 0.1  | -    | -    | -    | -    | -    | -    |
| <u>B. hortensis</u>       | -    | 0.1  | -    | -    | -    | -    | -    | -    | -    | -    | -    | -    |
| <u>S. quadrimaculatus</u> | -    | 0.1  | -    | -    | -    | -    | -    | -    | -    | -    | -    | -    |
| SMINTHURIDAE TOTAL        | 268  | 247  | 473  | 495  | 299  | 490  | 418  | 471  | 453  | 400  | 311  | 319  |
| <u>I. notabilis</u>       | 1141 | 1628 | 1684 | 2940 | 1782 | 2690 | 2220 | 3739 | 1076 | 1542 | 1661 | 2210 |
| <u>I. minor</u>           | 242  | 375  | 158  | 143  | 408  | 292  | 304  | 541  | 137  | 200  | 393  | 224  |
| <u>F. bisetosa</u>        | -    | 4    | 162  | 259  | 171  | 193  | 94   | 280  | 34   | 114  | 66   | 222  |
| <u>F. nivalis</u>         | 9    | 223  | 90   | 194  | 97   | 178  | 232  | 179  | 80   | 127  | 12   | 427  |
| <u>A. binoculatus</u>     | 30   | 77   | 41   | 88   | 23   | 101  | 31   | 152  | 18   | 41   | 16   | 48   |
| <u>I. nigrifrons</u>      | 90   | 55   | 91   | 21   | 18   | 32   | 67   | 0.4  | 5    | 25   | 18   | -    |
| <u>P. minima</u>          | 15   | 49   | 11   | 90   | 12   | 5    | 43   | 44   | 14   | 90   | 17   | 22   |
| <u>I. viridis</u>         | 5    | -    | 19   | 0.1  | 75   | 0.1  | 66   | -    | 30   | 0.1  | 20   | -    |
| <u>A. septentrionalis</u> | -    | 315  | -    | -    | -    | 66   | -    | 46   | 6    | 24   | -    | 69   |
| <u>A. altus</u>           | -    | -    | -    | 186  | -    | 14   | -    | -    | -    | -    | -    | -    |
| <u>I. nympha</u>          | -    | 0.5  | -    | -    | -    | 0.5  | -    | -    | -    | -    | -    | -    |
| <u>I. pseudocinerea</u>   | -    | -    | 3    | -    | -    | -    | -    | -    | -    | -    | -    | -    |
| <u>C. exilis</u>          | -    | -    | 4    | 15   | -    | -    | 42   | 15   | -    | 12   | 12   | 42   |
| <u>C. decemculatus</u>    | 5    | -    | -    | -    | -    | -    | -    | -    | -    | -    | 4    | 8    |
| <u>F. prima</u>           | -    | -    | -    | -    | -    | -    | -    | -    | -    | -    | 1    | -    |
| ISOTOMIDAE TOTAL          | 1537 | 2727 | 2263 | 3936 | 2586 | 3571 | 3099 | 4996 | 1400 | 2175 | 2219 | 3271 |

Table 7 continued:

|                         | 1984 |     | 1985 |     | 1986 |     | 1987 |      | 1988 |     | 1989 |     |
|-------------------------|------|-----|------|-----|------|-----|------|------|------|-----|------|-----|
|                         | T    | C   | T    | C   | T    | C   | T    | C    | T    | C   | T    | C   |
| <u>T. flavescens</u>    | 219  | 34  | 440  | 51  | 495  | 59  | 876  | 24   | 277  | 142 | 175  | 12  |
| <u>O. hexfasciata</u>   | 107  | 50  | 195  | 39  | 234  | 28  | 528  | 73   | 170  | 95  | 42   | 70  |
| <u>E. comparata</u>     | 19   | 80  | 37   | 82  | 84   | 34  | 128  | 58   | 72   | 222 | 46   | 255 |
| <u>P. violenta</u>      | 353  | -   | 278  | -   | 395  | 8   | 722  | 0.1  | 357  | -   | 325  | 0.1 |
| <u>E. nivalis</u>       | 23   | 5   | 40   | 4   | 69   | 8   | 19   | 4    | 40   | 8   | 45   | 20  |
| <u>W. buski</u>         | 0.3  | 17  | 12   | 4   | 46   | 12  | 74   | 29   | 30   | 39  | 52   | 51  |
| <u>T. lamelliferus</u>  | 89   | 16  | 45   | 1   | 73   | 4   | 182  | -    | 49   | -   | 11   | -   |
| <u>L. violaceus</u>     | 4    | 4   | 12   | -   | 8    | 0.3 | 18   | 1    | 21   | -   | 10   | 0.4 |
| <u>L. helenae</u>       | 3    | 11  | 5    | 7   | 4    | 8   | 8    | 1    | 10   | 8   | 2    | 16  |
| <u>L. lignorum</u>      | 0.4  | -   | 0.1  | -   | 4    | -   | 4    | -    | 9    | -   | 0.2  | -   |
| <u>E. purpurascens</u>  | 4    | 1   | 0.5  | 0.5 | 4    | 12  | 4    | 23   | 0.1  | -   | -    | -   |
| ENTOMOBRYIDAE           | 822  | 218 | 1065 | 189 | 1416 | 173 | 2563 | 213  | 1035 | 514 | 708  | 424 |
| <u>W. intermedia</u>    | -    | -   | 58   | 86  | 236  | 270 | 428  | 616  | 221  | 287 | 266  | 266 |
| <u>W. similis</u>       | -    | -   | 77   | 0.4 | 162  | 69  | 281  | 227  | 183  | 237 | 308  | 246 |
| <u>A. furcifera</u>     | -    | -   | 38   | 112 | 50   | 212 | 35   | 466  | 38   | 134 | 4    | 190 |
| <u>N. muscorum</u>      | 14   | 24  | 31   | 107 | 48   | 26  | 71   | 165  | 69   | 16  | 21   | 27  |
| <u>A. pygmaea</u>       | 0.3  | 8   | 4    | 8   | 12   | 100 | 58   | 155  | 25   | 42  | 54   | 82  |
| <u>F. sublimis</u>      | -    | -   | 0.1  | 25  | -    | 24  | -    | 8    | -    | 0.5 | -    | 8   |
| <u>P. saxatilis</u>     | 10   | 51  | -    | 5   | 4    | 8   | -    | 0.1  | -    | -   | 12   | 9   |
| <u>X. acauda</u>        | 4    | 86  | -    | 0.1 | -    | -   | -    | -    | 0.4  | 0.1 | 0.4  | 8   |
| <u>X. pallescens</u>    | -    | -   | 1    | 8   | 0.3  | 5   | 0.5  | -    | 3    | 6   | 10   | 7   |
| <u>P. aureofasciata</u> | -    | -   | 4    | 5   | -    | 12  | 0.1  | 4    | -    | 0.1 | 20   | 0.1 |
| <u>P. caeca</u>         | -    | -   | -    | 8   | 1    | -   | -    | 1    | -    | 5   | -    | -   |
| <u>O. substriata</u>    | -    | -   | -    | 23  | -    | -   | -    | -    | -    | -   | -    | 8   |
| <u>W. denisi</u>        | -    | -   | -    | -   | 8    | -   | -    | -    | -    | -   | -    | -   |
| <u>M. spirillifera</u>  | -    | -   | -    | -   | 8    | -   | -    | -    | -    | -   | -    | -   |
| <u>A. granaria</u>      | 4    | 85  | -    | -   | -    | 0.1 | -    | -    | -    | -   | -    | -   |
| <u>X. christianseni</u> | -    | -   | -    | -   | -    | 0.1 | -    | -    | -    | -   | -    | -   |
| <u>N. barberi</u>       | -    | -   | -    | -   | -    | 0.1 | -    | -    | -    | -   | -    | -   |
| <u>P. Indiana</u>       | -    | 0.2 | -    | -   | -    | -   | -    | -    | -    | -   | -    | -   |
| HYPOGASTRURIDAE         | 32   | 254 | 213  | 387 | 529  | 726 | 874  | 1642 | 539  | 728 | 695  | 851 |

Table 7 continued:

|                           | 1984 |       | 1985 |       | 1986  |       | 1987  |       | 1988  |       | 1989  |       |
|---------------------------|------|-------|------|-------|-------|-------|-------|-------|-------|-------|-------|-------|
|                           | T    | C     | T    | C     | T     | C     | T     | C     | T     | C     | T     | C     |
| <u>N. minimus</u>         | -    | -     | 145  | 137   | 11    | 270   | 80    | 259   | 13    | 111   | 57    | 109   |
| <u>N. minutus</u>         | 0.3  | 17    | 8    | 4     | -     | 15    | 1     | 18    | -     | 5     | -     | -     |
| <u>N. tristiani</u>       | 257  | 208   | 4    | 0.2   | 8     | 2     | -     | 0.2   | -     | -     | -     | 39    |
| <u>N. snideri</u>         | -    | -     | 0.2  | 36    | -     | 6     | -     | 4     | -     | -     | -     | -     |
| NEELIDAE                  | 257  | 225   | 157  | 177   | 19    | 293   | 81    | 281   | 13    | 116   | 57    | 148   |
| <u>T. mala</u>            | 1080 | 5850  | 1708 | 4382  | 2343  | 17870 | 4554  | 24347 | 4055  | 17138 | 5177  | 17935 |
| <u>T. granulata</u>       | 1332 | 1421  | 1286 | 1459  | 3551  | 5658  | 5563  | 11254 | 4547  | 7721  | 4476  | 6166  |
| <u>T. iowensis</u>        | -    | -     | 359  | 193   | 1554  | 589   | 2449  | 4188  | 2356  | 2767  | 1879  | 6693  |
| <u>T. clavata</u>         | 104  | 196   | 246  | 204   | 746   | 673   | 723   | 1989  | 321   | 742   | 681   | 535   |
| <u>T. yosii</u>           | 288  | 195   | 100  | 47    | 25    | 169   | 78    | 631   | 18    | 112   | 39    | 172   |
| <u>T. falca</u>           | -    | -     | 81   | -     | 42    | -     | 208   | -     | 371   | 13    | 654   | -     |
| <u>O. similis</u>         | 50   | 138   | 35   | 112   | 269   | 596   | 165   | 916   | 183   | 321   | 85    | 185   |
| <u>O. encarpatus</u>      | -    | 34    | -    | -     | -     | 1     | 8     | -     | 38    | -     | -     | -     |
| <u>O. affinis</u>         | -    | -     | -    | 29    | 8     | 47    | 4     | 88    | -     | 45    | 4     | 21    |
| <u>O. armatus</u>         | -    | -     | -    | -     | -     | -     | 4     | -     | -     | -     | -     | 31    |
| <u>O. talus</u>           | -    | -     | -    | -     | -     | -     | -     | 12    | -     | -     | -     | -     |
| <u>T. hades</u>           | -    | -     | 4    | -     | -     | -     | -     | -     | 4     | -     | -     | -     |
| <u>O. parvicornis</u>     | -    | -     | -    | 16    | -     | -     | -     | -     | -     | -     | -     | -     |
| ONYCHIURIDAE              | 2854 | 7884  | 3819 | 6442  | 8538  | 25603 | 13756 | 43425 | 11893 | 28860 | 12995 | 31739 |
| TOTAL<br>(- Onychiuridae) | 2916 | 3671  | 4171 | 5184  | 4849  | 5253  | 7035  | 7603  | 3440  | 3933  | 3990  | 5013  |
| TOTAL<br>(+ Onychiuridae) | 5770 | 11555 | 7990 | 11626 | 13387 | 30856 | 20791 | 51028 | 15333 | 32793 | 16985 | 36752 |
| TOTAL N SPECIES           | 36   | 41    | 46   | 37    | 46    | 55    | 46    | 47    | 45    | 44    | 46    | 48    |

### 2.3. Diversity

Annual mean diversity of the collembolan communities in Test and Control (Table 8) is based on diversity estimates obtained for each date, using mean annual density of each species (abundances in litter and soil summed where appropriate). Clearly, diversity has been consistently lower in Control, probably due to the preponderance of Onychiuridae. Indices decreased over three years, then stabilized in 1989 (Table 8). The trend was parallel in Test and Control: year and site effects were highly significant, but not year x site interactions (Table 9).

Table 8. Mean ( $\pm$  SD) annual diversity indices (Shannon-Wiener) for Test and Control collembolan communities, using all years for which extraction efficiency data are available; N = 12 dates/ year.

|         | 1986            | 1987            | 1988            | 1989            |
|---------|-----------------|-----------------|-----------------|-----------------|
| Test    | 2.35 $\pm$ 0.21 | 2.25 $\pm$ 0.28 | 2.03 $\pm$ 0.36 | 2.08 $\pm$ 0.27 |
| Control | 2.01 $\pm$ 0.23 | 1.67 $\pm$ 0.17 | 1.47 $\pm$ 0.16 | 1.48 $\pm$ 0.26 |

Table 9. Anova table for collembolan diversity indices, 1986-1989.

| Source      | df | SS     | MS    | F       | P     |
|-------------|----|--------|-------|---------|-------|
| Replication | 11 | 0.637  | 0.058 | 0.922   |       |
| Years       | 3  | 2.796  | 0.932 | 14.840  | 0.000 |
| Sites       | 1  | 6.453  | 6.453 | 102.741 | 0.000 |
| Yearxsite   | 3  | 0.245  | 0.082 | 1.300   | 0.280 |
| Error       | 77 | 4.836  | 0.063 |         |       |
| Total       | 95 | 14.968 |       |         |       |

#### 2.4. Isotoma notabilis

The species is the dominant isotomid in both sites and frequents both litter and soil. Size measurements of all specimens, supplemented by observation of setal distribution, allow division of the population into instars I (= hatchlings), other juveniles and adult classes. Developmental stage frequency distributions for 1988 and 1989 are now available in addition to the 1984- 1987 data presented last year.

As mentioned earlier, annual density fluctuations of the total populations are well correlated between sites, as are abundances of each developmental class (Fig. 3). Expressed as frequency distributions (% of total), some between-year variations become evident: in 1985, adults were unusually prominent in Control; in 1989, instars I were relatively more numerous with respect to the other classes (Fig. 4).

The seasonal (bi-weekly) frequencies of stages, however, is biologically of the greatest interest. They reflect patterns of recruitment and maturation which should coincide in Test and Control given the virtual equality of temperature conditions. Instars I, for instance, tend to peak at the beginning of May (Fig. 5) unless an early, warm spring causes them to molt and advance to the next class prior to the first sampling date (e.g., 1987, Fig. 5). A second peak occurs in early July, and a third, lesser peak may be noticeable in the fall (Fig. 5).

Because of the interdependency of percentiles, seasonal frequencies were analyzed for each class separately, by Anova without replication (Table 10).

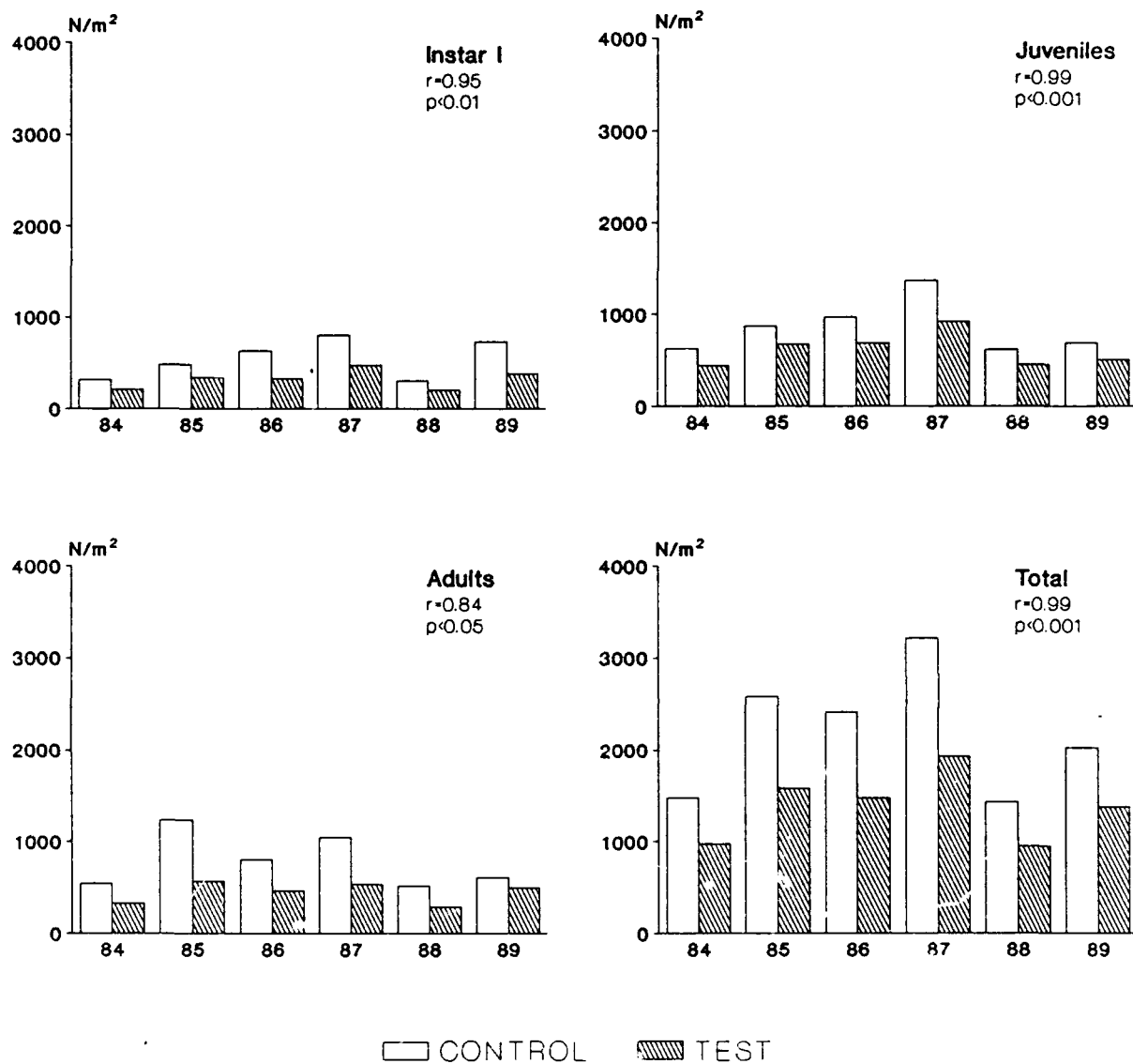


Fig. 3. Mean annual abundance  $/m^2$  of *Isotoma notabilis* in Test and Control, 1984 through 1989 (summed abundances in litter + soil).

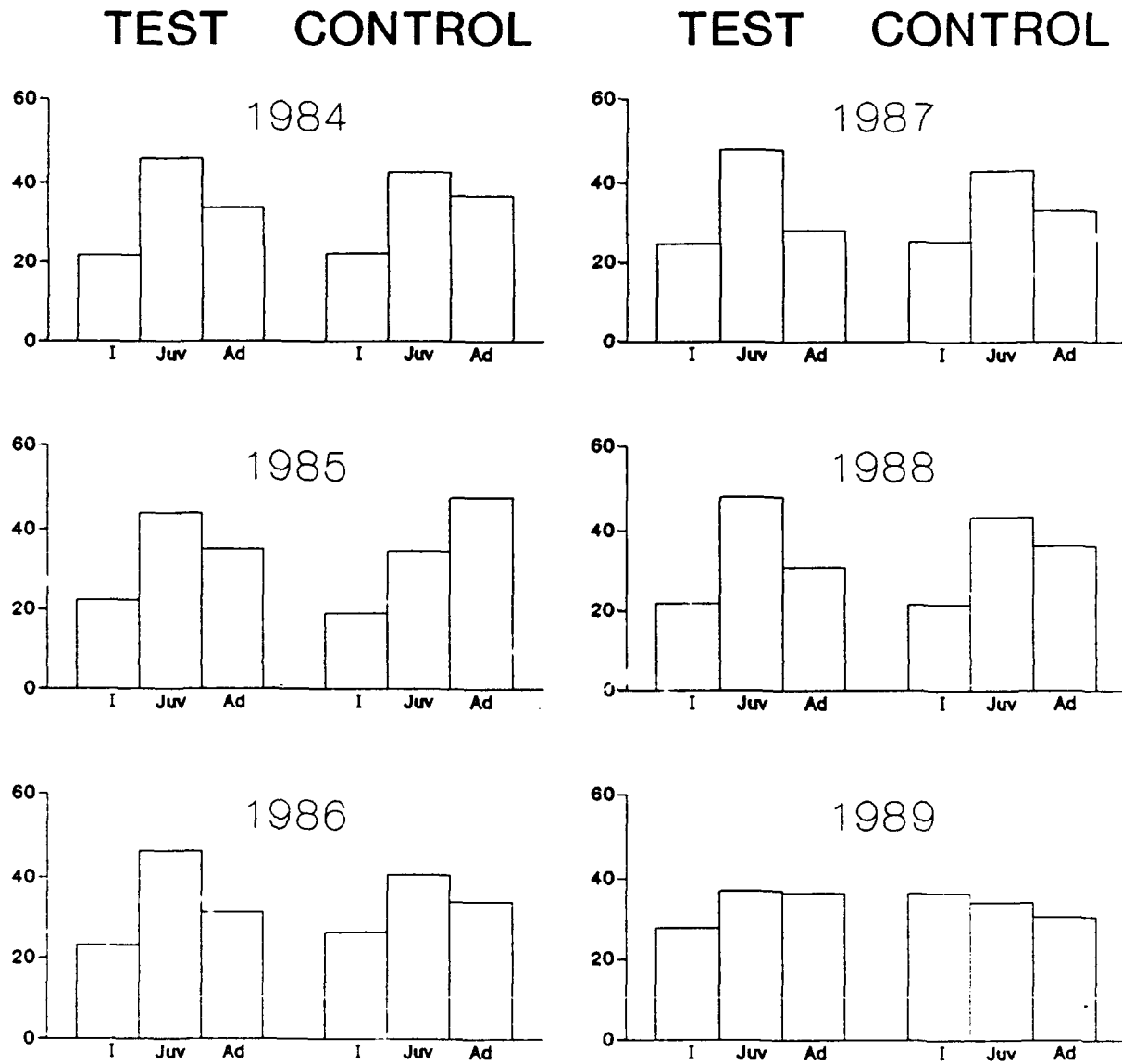


Fig. 4. Annual frequency distributions among three developmental classes of Isotoma notabilis : instars I (I), other juveniles (Juv) and adults (Ad), 1984 to 1989.



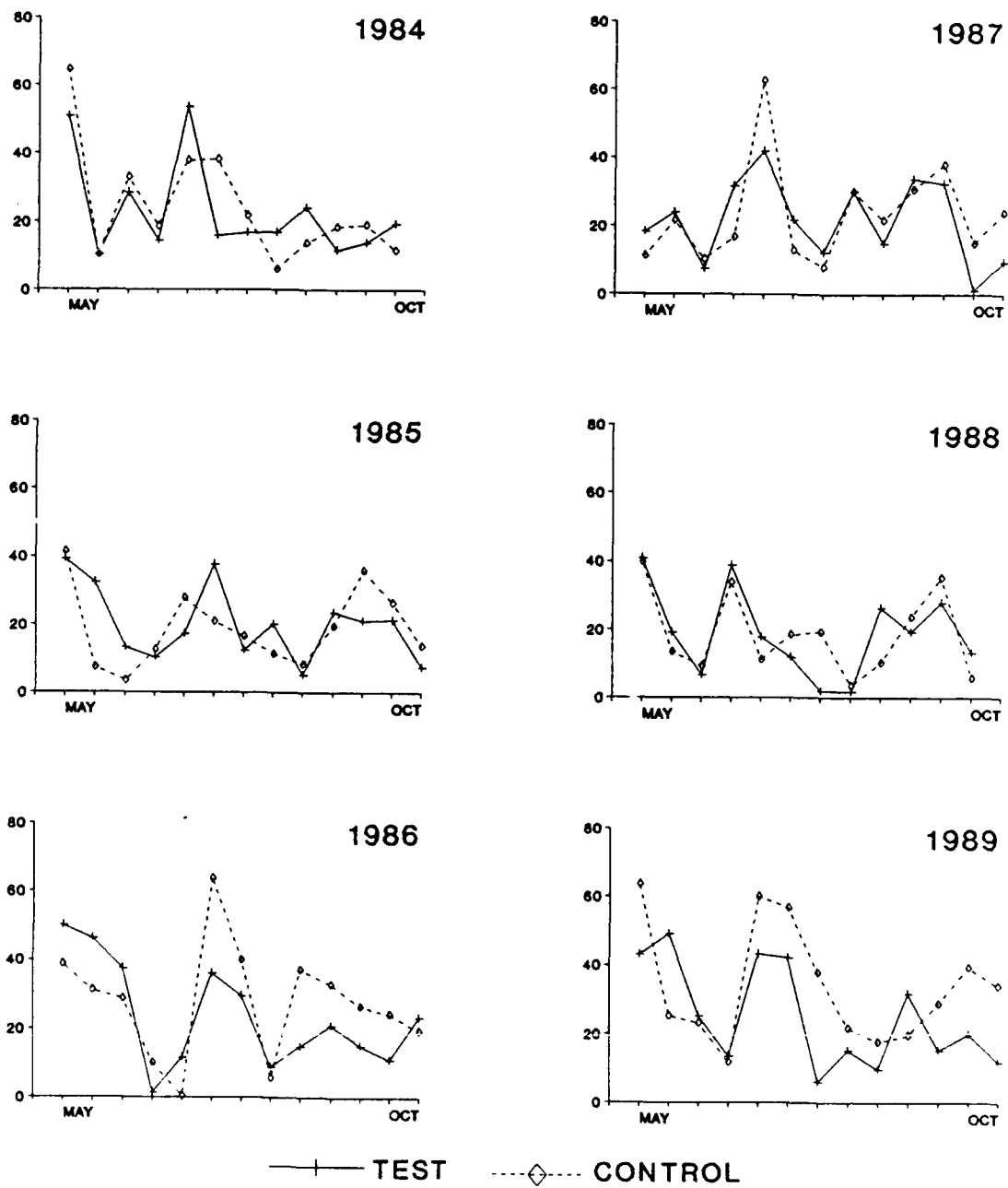


Fig. 5. Biweekly frequencies (in % of total population) of instars I of *Isotoma notabilis* in Test and Control, 1984 to 1989.

Table 10. Analysis of variance table for frequency distributions of developmental classes of Isotoma notabilis on each date in 1984 through 1989. (Transformed proportions:  $y_i = \ln [ p / (1-p) ]$ ).

INSTARS I

| Source      | df  | SS      | MS    | F     | P     |
|-------------|-----|---------|-------|-------|-------|
| Year        | 5   | 7.918   | 1.584 | 3.434 | 0.009 |
| Site        | 1   | 0.212   | 0.212 | 0.459 | NS    |
| Year x site | 5   | 1.791   | 0.358 | 0.777 | NS    |
| Date        | 11  | 31.286  | 2.844 | 6.169 | 0.000 |
| Year x date | 55  | 71.965  | 1.308 | 2.838 | 0.000 |
| Site x date | 11  | 6.793   | 0.618 | 1.339 | 0.229 |
| Error       | 55  | 25.360  | 0.461 |       |       |
| Total       | 143 | 145.325 |       |       |       |

OTHER JUVENILES

|             |     |        |       |       |       |
|-------------|-----|--------|-------|-------|-------|
| Year        | 5   | 2.717  | 0.543 | 1.689 | 0.153 |
| Site        | 1   | 2.436  | 2.436 | 7.570 | 0.008 |
| Year x site | 5   | 1.630  | 0.326 | 1.013 | 0.419 |
| Date        | 11  | 9.673  | 0.879 | 2.733 | 0.007 |
| Year x date | 55  | 30.192 | 0.549 | 1.706 | 0.025 |
| Site x date | 11  | 6.383  | 0.580 | 1.803 | 0.076 |
| Error       | 55  | 17.700 | 0.322 |       |       |
| Total       | 143 | 70.732 |       |       |       |

ADULTS

|             |     |        |       |       |       |
|-------------|-----|--------|-------|-------|-------|
| Year        | 5   | 4.765  | 0.953 | 2.964 | 0.019 |
| Site        | 1   | 1.304  | 1.304 | 4.054 | 0.049 |
| Year x site | 5   | 2.342  | 0.468 | 1.456 | 0.219 |
| Date        | 11  | 25.893 | 2.354 | 7.321 | 0.000 |
| Year x date | 55  | 30.552 | 0.555 | 1.727 | 0.022 |
| Site x date | 11  | 3.128  | 0.284 | 0.884 | NS    |
| Error       | 55  | 17.685 | 0.322 |       |       |
| Total       | 143 | 85.668 |       |       |       |

Juveniles, which encompass several stages of varying duration, exhibited site effects, but no significant year x site or site x date interactions. Since this is the largest class and the most spread-out over the seasons, we consider instars I and adults to be of greater indicator importance: the relative prominence and time of appearance of adults will largely determine those same parameters in the hatchling category.

As expected, date and year effects were significant for both classes (Table 10). Sites differed significantly at  $P = 0.05$  for adults only, reflecting the more variable abundance of that class in Control (Figs. 3, 4): we suggest that this is a case where statistical and biological levels of significance diverge. That the general patterns of oviposition, hatching and development to adulthood are synchronous in Test and Control, however, is evidenced by site x year and site x date effects not being significant. It seems that I. notabilis remains a good indicator species to monitor, since potential disruption of this synchronicity should be detectable in future years.

### 3. Acari of litter and soil

#### 3.1. Extraction efficiency

Nanorchestes sp. A, the dominant member of the genus in both sites, frequents both leaf litter and soil. Efficiency of heat extraction is relatively high for the species, ranging from 79 to 100% in Test and from 84 to 98% in Control (Table 11). Not so the Mesostigmatid sp. A: extraction efficiency for this species has been 40% at best (Table 11).

Provisionally, overall averages of 30.2% (Test) and 35.6% (Control) can be used to adjust density estimates for 1984 and 1985, years in which sugar floatation was not performed. Pertinent data for these two taxa, as well as for the litter-dwelling Asca aphidioides, are discussed below.

Table 11. Heat extraction efficiency (in % of total numbers obtained by extraction + sugar floatation) for Nanorchestes and Mesostigmatid sp. A.

|                       | <u>Percent of total N</u> |      |      |      |
|-----------------------|---------------------------|------|------|------|
|                       | 1986                      | 1987 | 1988 | 1989 |
| <u>Nanorchestes A</u> |                           |      |      |      |
| Test                  | 100.0                     | 78.8 | 92.3 | 91.5 |
| Control               | 94.9                      | 84.4 | 97.8 | 98.4 |
| <u>Mesostigmata A</u> |                           |      |      |      |
| Test                  | 36.9                      | 23.9 | 38.9 | 27.5 |
| Control               | 25.6                      | 32.4 | 40.3 | 40.6 |

### 3.2. Density

There is no indication that seasonal abundance fluctuations in 1989 were in any way outlying. Litter-inhabiting Nanorchestes, for instance, showed significant synchronicity between sites (Fig. 6). Similarly, larval and adult sp. A Mesostigmata exhibited correlated abundance variations in Test and Control soils (Fig. 7).

Fig. 8 provides an updated illustration of long-term population trends in the three species we continue to monitor. Mean annual density of Asca aphidioides, a litter inhabitant, increased slightly in 1989. Nanorchestes, for which abundances are summed estimates of [litter + soil], has been approximately stable over the last three years. Data for the Mesostigmatid A

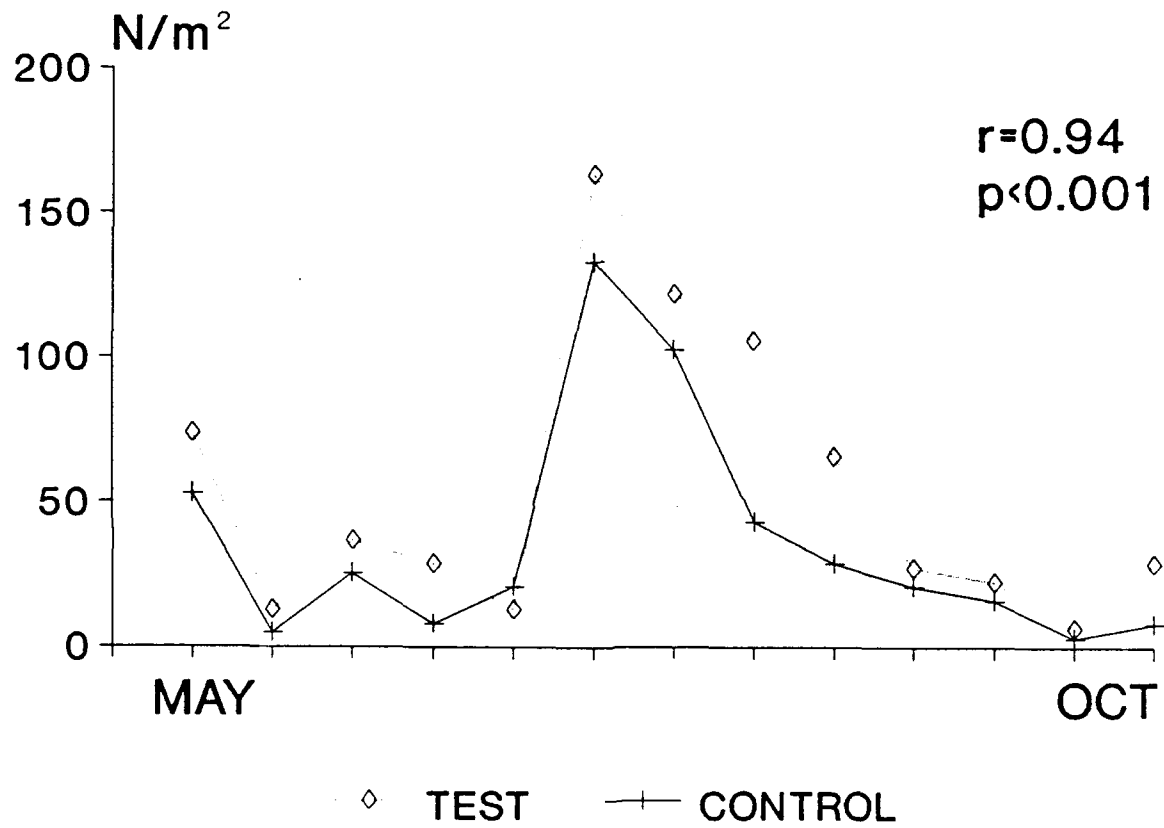


Fig. 6. Biweekly density /  $m^2$  of *Nanorchestes A* in leaf litter of Test and Control, 1989.

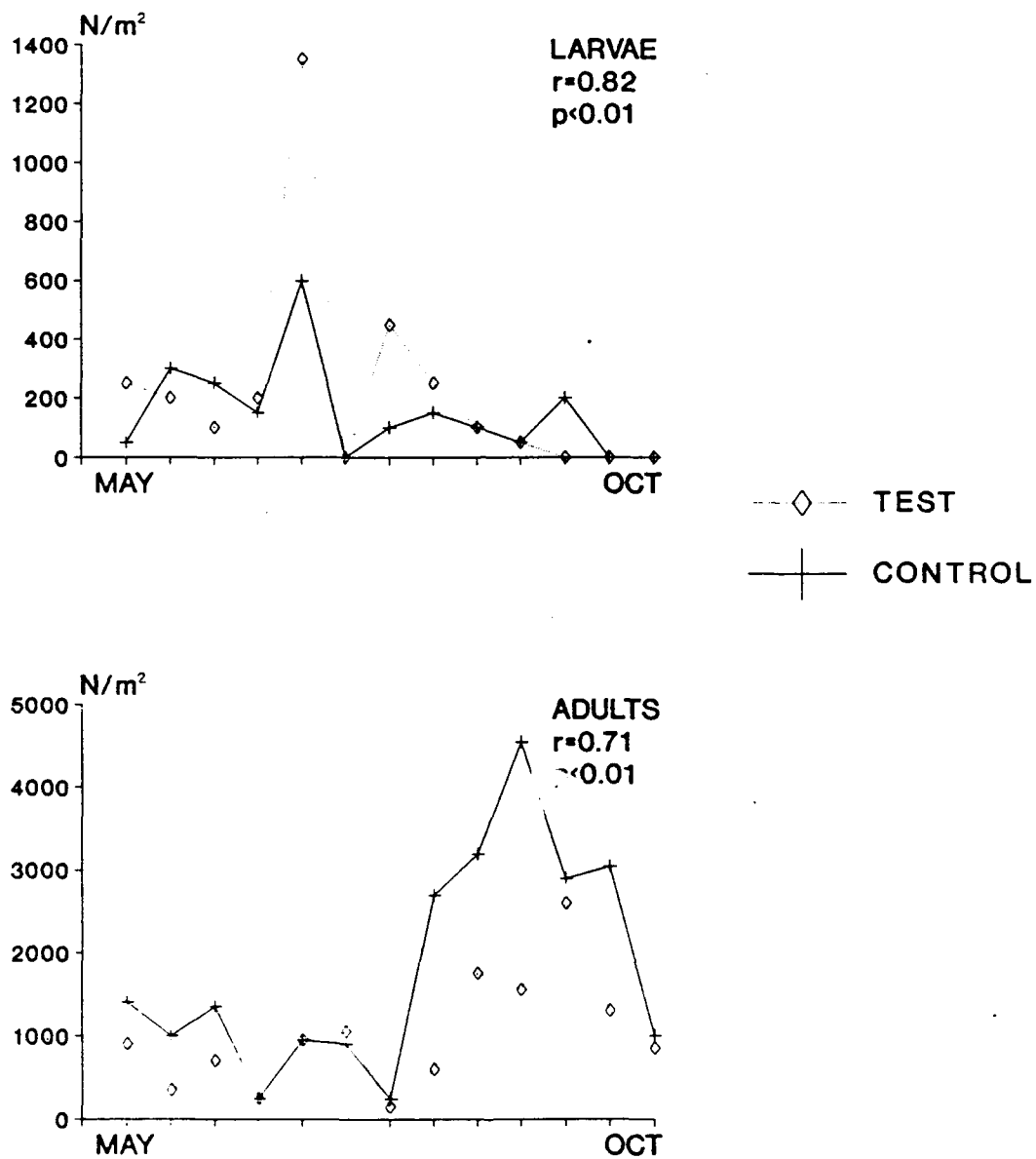


Fig. 7. Biweekly abundance  $/m^2$  of larval and adult Mesostigmata sp. A in Test and Control soils, 1989.

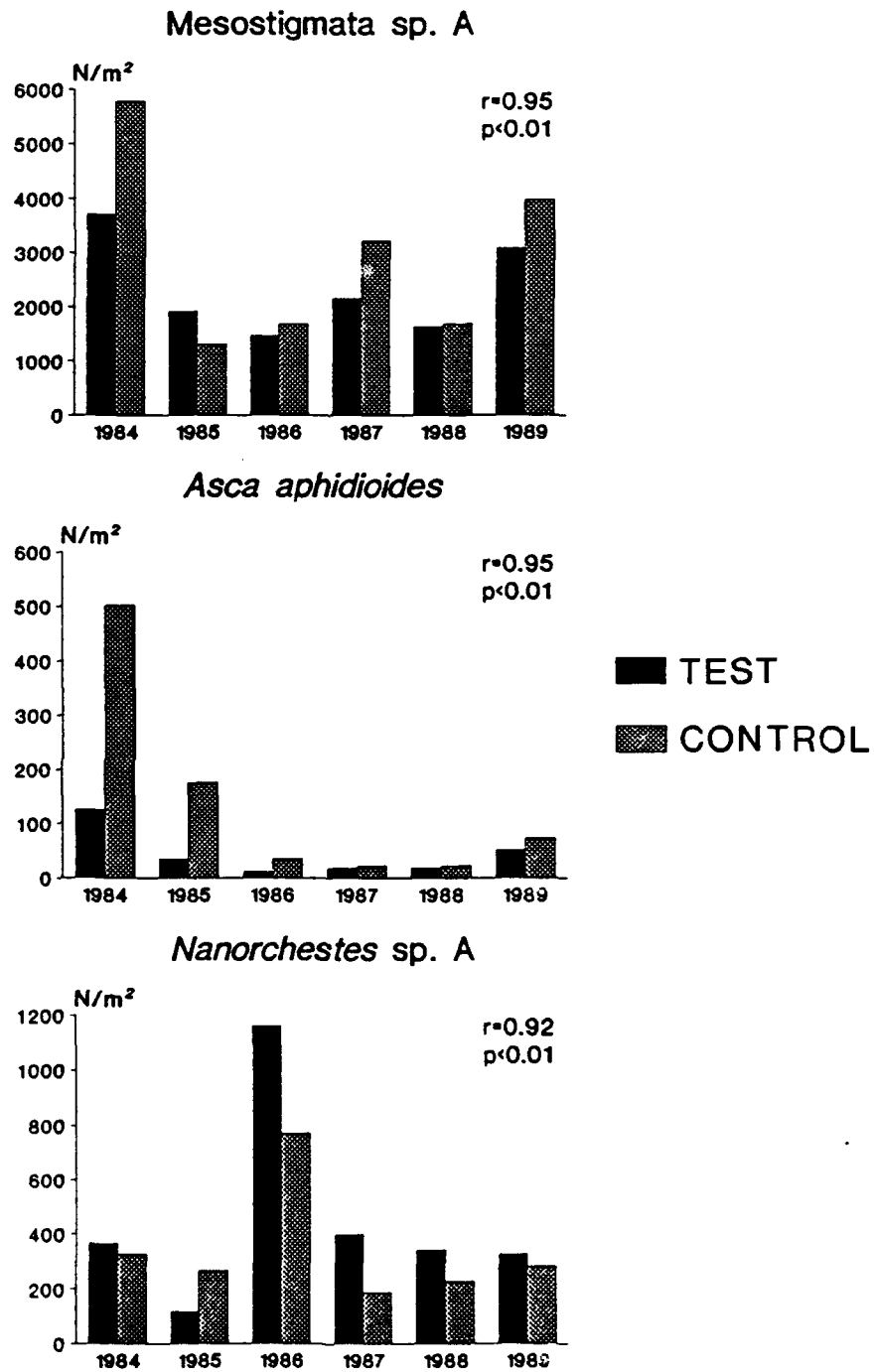


Fig. 8. Mean annual abundance of three mite species in Test and Control, 1984 to 1989.

include 1984 and 1985 estimates adjusted for mean extraction efficiency; they indicate that populations were highest in 1984, then fluctuated synchronously in both sites. We may simply point out that in all three species, annual abundance variations were closely correlated between sites (Fig. 8).

Among specific developmental stages, annual abundance of deutonymphs and adults generally provide good site comparisons. For example, adult subpopulations of Asca aphidioides and Mesostigmatid A (Fig. 9) are well correlated, proportional differences between sites being consistent with earlier years.

### 3.3. Population structure

Our concern that severely reduced populations, particularly of A. aphidioides, would endanger this data base, was alleviated. Numbers of specimens of both A. aphidioides and the Mesostigmatid sp. A were sufficiently high in 1989 to warrant examination. As in past years, seasonal frequencies of developmental stages (larva, protonymph, deutonymph and adult) were summarized by month and subjected to Anova (without replication) for each stage separately.

Given the goals of this project, the Mesostigmatid sp. A proved to be of little use, not because site effects were significant, but because they were not consistent either between years or among developmental stages. With the exception of deutonymphs, virtually all main effects and their interactions were significant. However, ranking of years and sites according to least significant differences resulted in a meaningless jumble. Where we had thought to see a relatively simple pattern of a single main generation per year (e.g., Fig. 7), we are actually dealing with two or more overlapping cohorts. This interpretation was confirmed by re-examination of specimens: females were found to be gravid in virtually every month of the season.



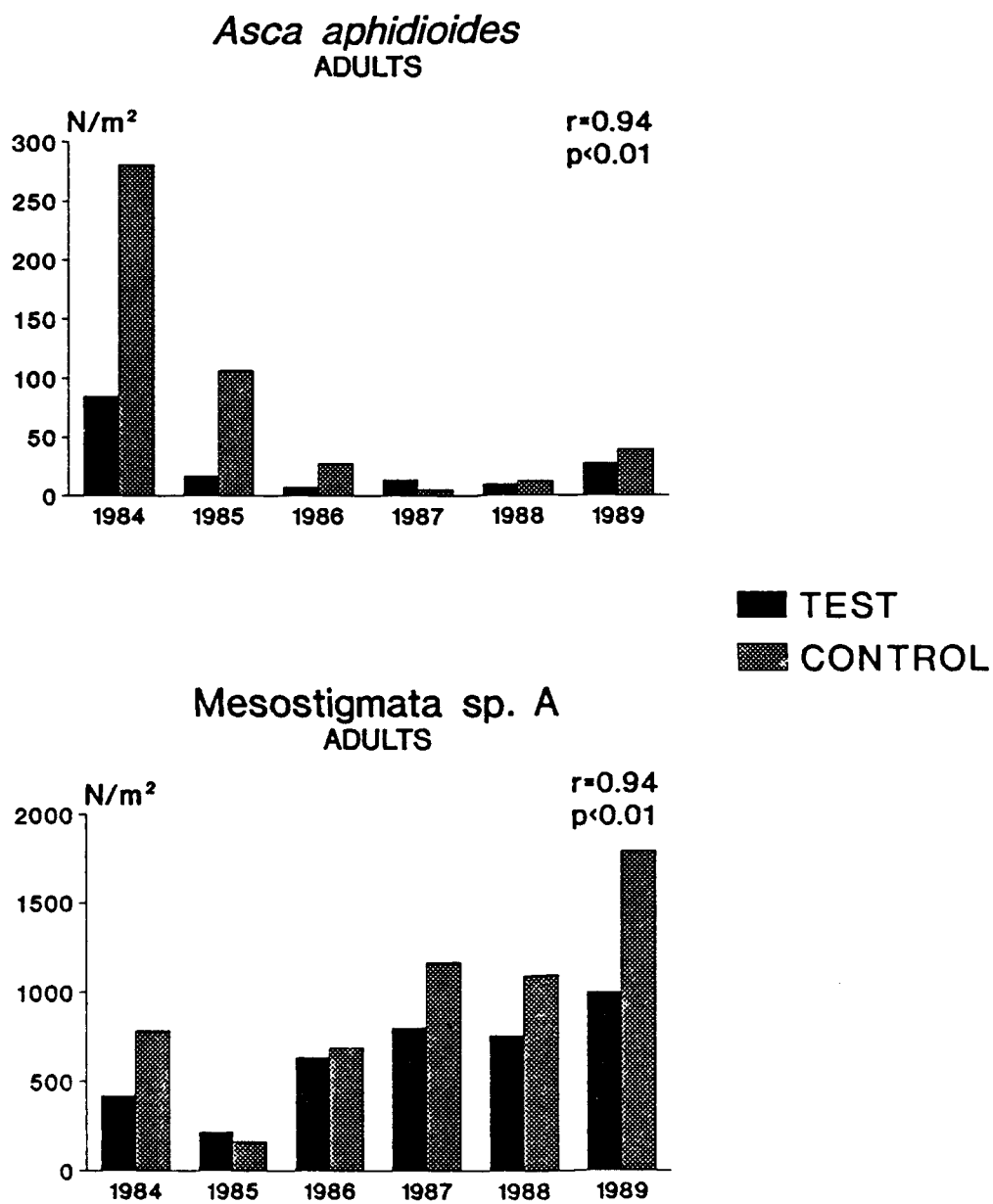


Fig. 9. Mean annual density of adults of two mite species in Test and Control, 1984 to 1989.

Depending on year-specific environmental conditions, the variable success of each cohort would then contribute variable numbers of each developmental stage at different times of the year.

Population structure of *Mesostigmatid* sp. A is thus not a good indicator parameter for potential disturbance. As a matter of course, however, we will continue to monitor the degree to which abundance of the species in Test and Control are correlated.

The parthenogenetic *Asca aphidioides* has a much less complex, univoltine life cycle. Data for 1989, a year with low population abundance, and 1984, the year of its greatest abundance to date, are shown as examples in Fig. 10. The cycle begins with a preponderance of adult females in early to late spring, which give rise to a single cohort of larvae and subsequent stages; they mature again to adulthood in September. Adults apparently enter hibernation in late September: usually, only a single to a few specimens are extracted from October samples. Excluding the low - frequency October dates, we subjected monthly frequencies to analysis of variance (Table 12).

Results indicate that the stability and simplicity of the *Asca* life cycle make it a good candidate for continued monitoring and analysis. Year, date effects and their interaction can be significant, particularly in the nymph and adult stages, due to year-specific temperature profiles and ensuing developmental rates. For none of the stages, however, were site x year or site x date interactions significant, i.e., developmental patterns were highly similar in Test and Control.

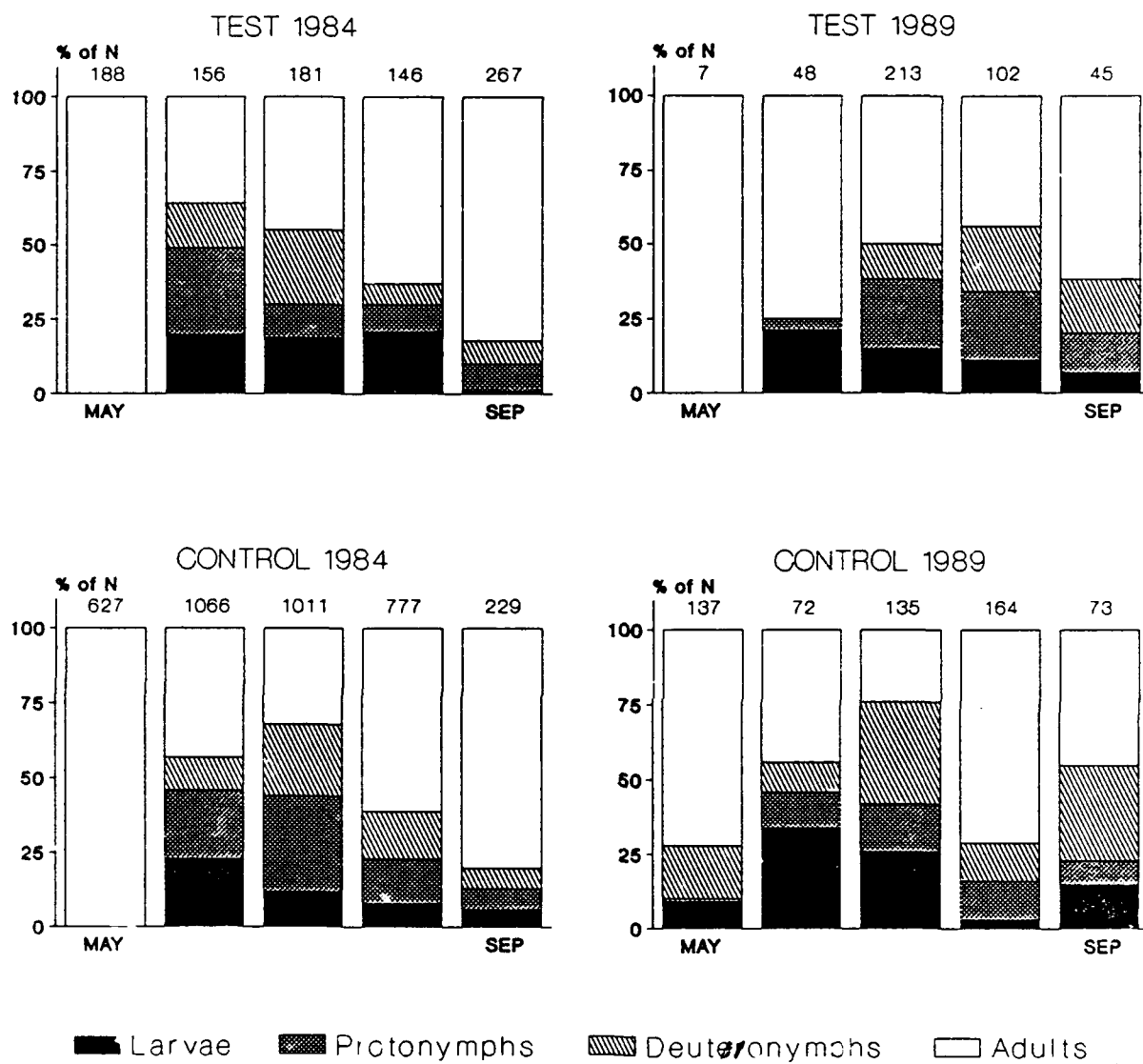


Fig. 10. Monthly frequencies of developmental stages of Asca aphidioides in Test and Control, 1984 and 1989. Numbers above each bar = total number of specimens from which percentages were derived.

Table 12. Anova table for monthly frequency distributions of the four stages of Asca aphidioides. (Transformed proportions:  $y_i = \ln [p/(1-p)]$ ).

LARVAE

| Source      | df | SS      | MS     | F      | P     |
|-------------|----|---------|--------|--------|-------|
| Site        | 1  | 6.020   | 6.020  | 3.038  | 0.097 |
| Year        | 5  | 25.193  | 5.039  | 2.543  | 0.062 |
| Site x year | 5  | 7.854   | 1.571  | 0.793  | NS    |
| Date        | 4  | 130.480 | 36.620 | 16.462 | 0.000 |
| Site x date | 4  | 8.890   | 2.223  | 1.122  | 0.374 |
| Year x date | 20 | 44.566  | 2.228  | 1.125  | 0.398 |
| Error       | 20 | 39.629  | 1.981  |        |       |
| Total       | 59 | 262.634 |        |        |       |

PROTONYMPHS

|             |    |         |        |        |       |
|-------------|----|---------|--------|--------|-------|
| Site        | 1  | 0.007   | 0.007  | 0.005  | NS    |
| Year        | 5  | 36.582  | 7.316  | 5.293  | 0.003 |
| Site x year | 5  | 2.310   | 0.462  | 0.334  | NS    |
| Date        | 4  | 139.947 | 34.987 | 25.310 | 0.000 |
| Site x date | 4  | 2.311   | 0.578  | 0.418  | NS    |
| Year x date | 20 | 46.191  | 2.310  | 1.671  | 0.130 |
| Error       | 20 | 27.646  | 1.382  |        |       |
| Total       | 59 | 254.994 |        |        |       |

DEUTONYMPHS

|             |    |         |        |        |       |
|-------------|----|---------|--------|--------|-------|
| Site        | 1  | 3.004   | 3.004  | 1.820  | 0.192 |
| Year        | 5  | 28.541  | 5.708  | 3.458  | 0.021 |
| Site x year | 5  | 13.579  | 2.716  | 1.645  | 0.194 |
| Date        | 4  | 89.442  | 22.361 | 13.545 | 0.000 |
| Site x date | 4  | 4.681   | 1.170  | 0.709  | NS    |
| Year x date | 20 | 88.590  | 4.429  | 2.683  | 0.016 |
| Error       | 20 | 33.017  | 1.651  |        |       |
| Total       | 59 | 260.854 |        |        |       |

ADULTS

|             |    |         |        |        |       |
|-------------|----|---------|--------|--------|-------|
| Site        | 1  | 1.791   | 1.791  | 1.639  | 0.215 |
| Year        | 5  | 12.431  | 2.486  | 2.275  | 0.086 |
| Site x year | 5  | 7.928   | 1.586  | 1.451  | 0.250 |
| Date        | 4  | 211.460 | 52.865 | 48.372 | 0.000 |
| Site x date | 4  | 8.196   | 2.049  | 1.875  | 0.154 |
| Year x date | 20 | 76.656  | 3.833  | 3.507  | 0.004 |
| Error       | 20 | 21.857  | 1.093  |        |       |
| Total       | 59 | 340.320 |        |        |       |

#### IV. SURFACE-ACTIVE ARTHROPODA

Since 1985, we have 20 permanently installed barrier-traps per site, activated at dawn and dusk so that one consecutive night and day catch are obtained at intervals of one week from early May to late October. Samples taken in 1990 are still being processed. For the 1989 season, we can present data on Collembola and Acari. Identification of carabid beetles has been delayed due to a shift in personnel, but we expect to have these data available within the next six weeks.

##### 1. Statistical approach

As discussed in last year's report, we continue to use within-year correlations between trap catches in Test and Control as the main evidence upon which our conclusions are based. Seasonal occurrence and relative frequency of a given taxon or developmental stage can validly be taken as a reflection of rates of reproduction and development, as well as of modulations of surface-activity by environmental variables.

In the past, we have rarely been able to explain more than 40 to 50% of seasonal (date - to - date) catch variability by regression on various temperature variables. Once we have 1990 data at hand, we will try a different approach. Catches within a given date, in proportion of the total number caught on that date over all years, will be regressed on temperature variables for each date. We thereby hope to distinguish between species-specific tendencies (e.g., lowest activity in the summer, highest in spring and fall) and deviations from them within each date or season.

## 2. Collembola

Total annual catches of the most commonly captured species in either or both sites are listed in Table 13. The great year-to-year variability commented on in earlier reports held true in 1989. It may be noteworthy, however, that drastically decreased numbers of Tomocerus flavescens and Orchesella hexfasciata in the Test site led to a reversal of previous relationships: total Sminthuridae now outnumbered the usually prevalent Entomobryidae. In Control, Entomobryidae became dominant over Sminthuridae in 1988, and remained so in 1989 (Table 13).

Three species were useful for between-site comparison (Fig. 11): Sminthurinus henshawi, Sminthurides lepus and Orchesella hexfasciata. Weekly catches of all three (nocturnal and diurnal samples lumped) were significantly correlated, although the coefficients were not particularly high. At the family level, general patterns observed in past years were essentially repeated in 1989: sminthurid activity, strongly dominated by S. henshawi and S. lepus in both sites, tends to peak in spring and fall; Entomobryidae tend to be least active early and late in the year (Fig. 12). Two unique species were omitted from family totals in Fig. 12: Dicyrtoma aurata, unique to Control and strongly seasonal (active exclusively in September and October); and Lepidocyrtus paradoxus, the overwhelmingly dominant entomobryid in Control (Table 13) which is essentially absent in the Test site.

Overall, trap catches of none of these taxa indicated any disturbances. Correlation coefficients were similar to those previously observed, and general seasonal patterns of activity were maintained in 1989.

Table 13. Total annual pit-trap catches of selected taxa of Collembola in Test and Control, 1985 to 1989.

|                       | T E S T |      |       |       |      | C O N T R O L |      |       |       |       |
|-----------------------|---------|------|-------|-------|------|---------------|------|-------|-------|-------|
|                       | 1985    | 1986 | 1987  | 1988  | 1989 | 1985          | 1986 | 1987  | 1988  | 1989  |
| <u>S. henshawi</u>    | 1637    | 1435 | 1992  | 2811  | 3065 | 2606          | 2934 | 4123  | 5084  | 3675  |
| <u>S. lepus</u>       | 669     | 236  | 1049  | 503   | 1438 | 397           | 375  | 1019  | 824   | 724   |
| <u>D. aurata</u>      | 5       | 0    | 4     | 1     | 0    | 468           | 976  | 2198  | 448   | 396   |
| SMINTHURIDAE          | 2423    | 1709 | 3124  | 3398  | 4841 | 3593          | 4379 | 7607  | 6770  | 5368  |
| <u>T. flavescens</u>  | 4213    | 1965 | 2429  | 1684  | 641  | 842           | 242  | 280   | 165   | 237   |
| <u>O. hexfasciata</u> | 3201    | 3402 | 4137  | 3426  | 738  | 1099          | 421  | 1180  | 3549  | 1672  |
| <u>E. comparata</u>   | 35      | 80   | 119   | 150   | 57   | 287           | 87   | 157   | 1493  | 440   |
| <u>E. nivalis</u>     | 531     | 1057 | 294   | 291   | 218  | 4             | 14   | 34    | 77    | 104   |
| <u>L. paradoxus</u>   | 22      | 6    | 37    | 123   | 22   | 1142          | 961  | 2701  | 2649  | 3783  |
| <u>P. violenta</u>    | 166     | 381  | 606   | 916   | 327  | 1             | 1    | 47    | 0     | 2     |
| ENTOMOBRYIDAE         | 8433    | 7238 | 8209  | 7186  | 2275 | 3479          | 1752 | 4495  | 8100  | 6308  |
| <u>P. saxatilis</u>   | 13      | 0    | 5     | 0     | 53   | 1925          | 198  | 348   | 379   | 464   |
| HYPOGASTRURIDAE       | 80      | 90   | 191   | 196   | 420  | 2122          | 292  | 456   | 463   | 798   |
| ISOTOMIDAE            | 582     | 513  | 486   | 292   | 484  | 751           | 392  | 562   | 188   | 485   |
| TOTAL ALL SPP.        | 11518   | 9550 | 12010 | 11072 | 8020 | 9946          | 6815 | 13120 | 15522 | 12959 |
| TOTAL N SPP.          | 36      | 29   | 32    | 33    | 36   | 30            | 28   | 32    | 33    | 33    |

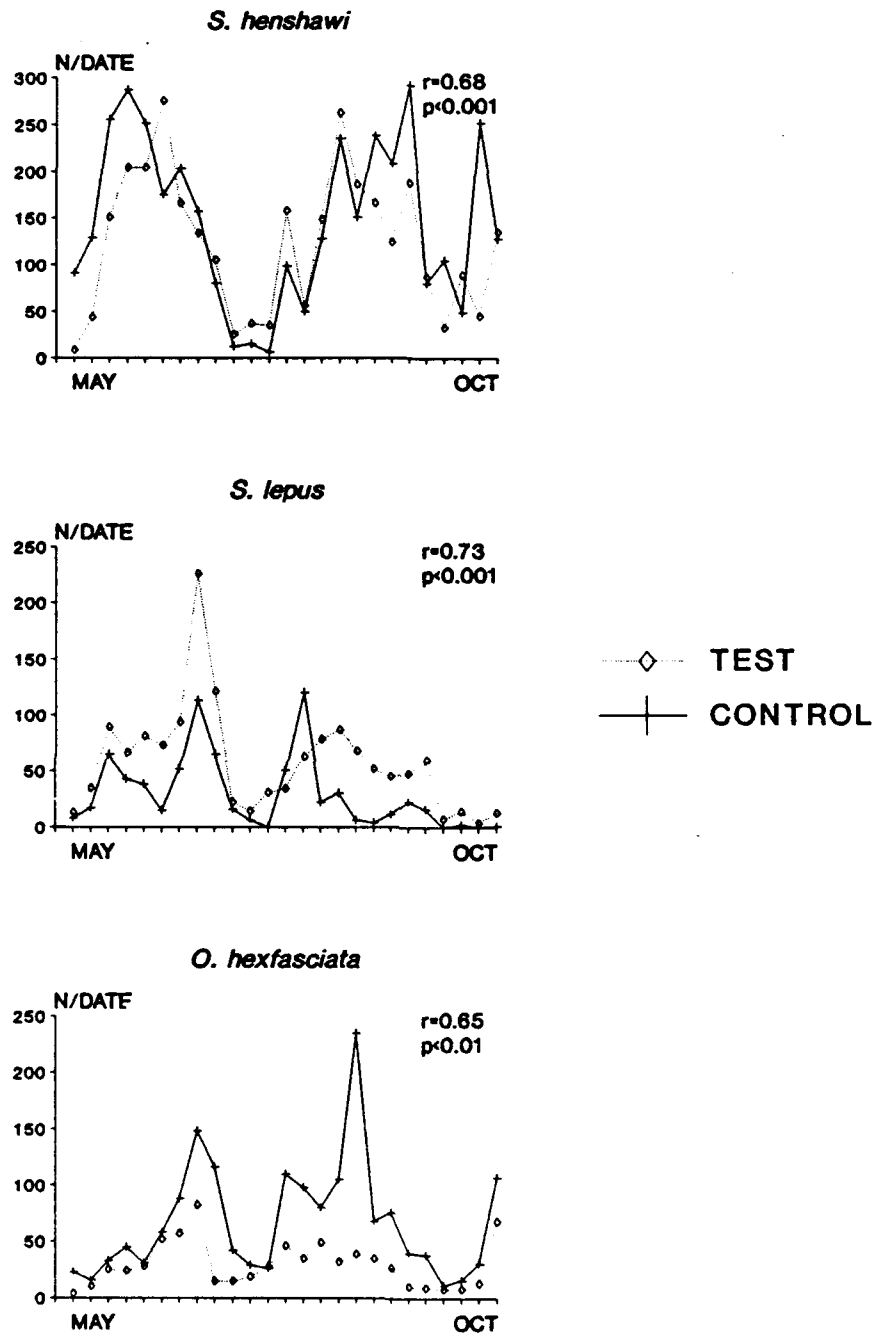


Fig. 11. Weekly trap catches (night + day summed) of three collembolan species in Test and Control, 1989.



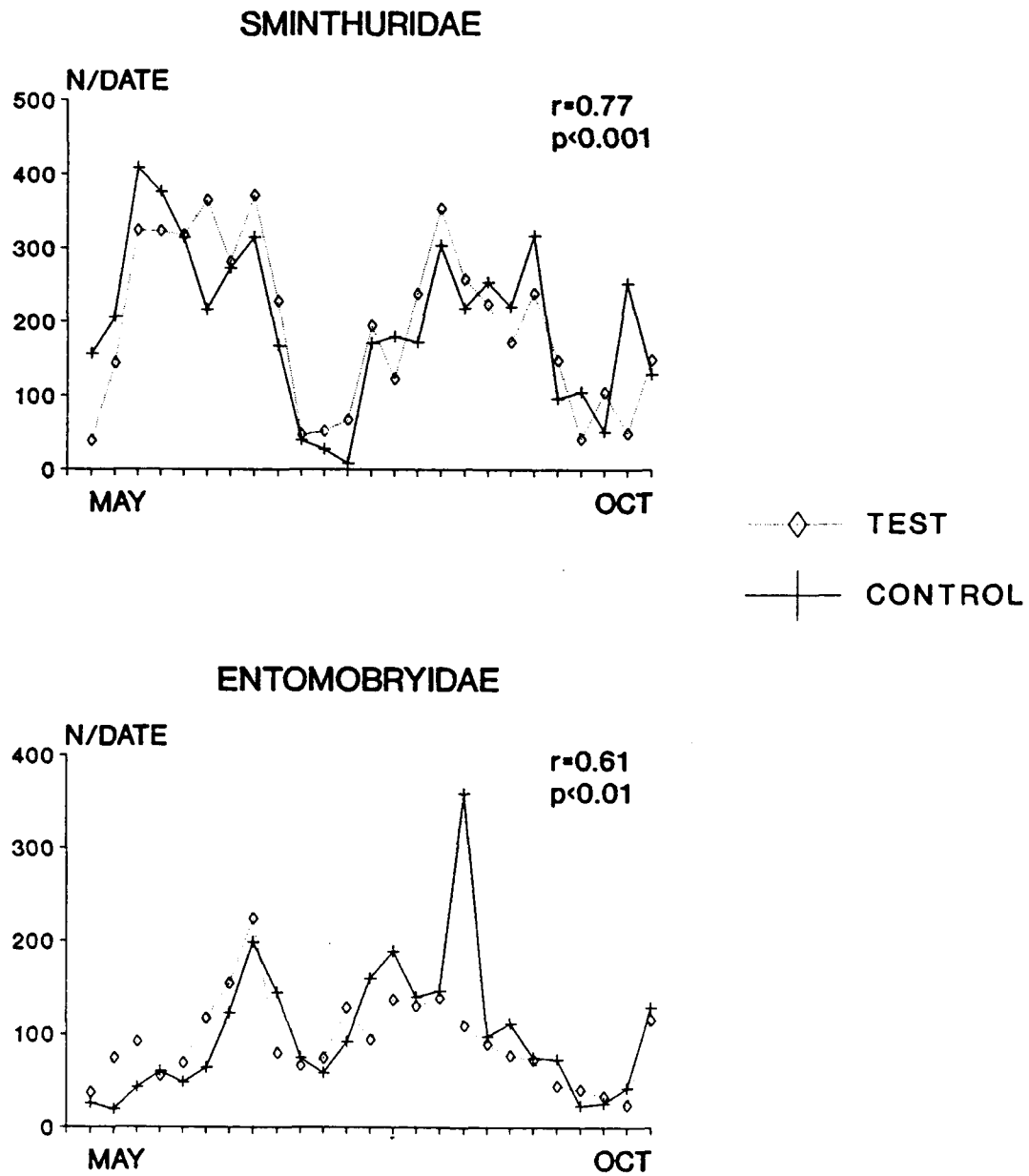


Fig. 12. Weekly trap catches (night + day summed) of two collembolan families in Test and Control, 1989.

### 3. Acari

NOTE: Difficulties with species identifications of velvet mites (other than Trombidium auroraense) are slowly being resolved. One of our Ph.D. students has undertaken the difficult task of rearing several species through all five life stages, from parasitic larva to adult. Data will allow correct assignment of immatures to the corresponding adult form, as well as complete description of species which are undescribed and have yet to be named.

We have so far encountered over a dozen species of velvet mites in both sites. Most are rare, however, and we continue to present data on the two numerically dominant forms: T. auroraense and Abrolophus sp. Specimens of the latter stemming from 1985-88 are currently being re-examined for accuracy of identification; only 1989 data will be shown below.

#### 3.1. Trombidium auroraense

This strictly diurnal species ( > 95% captured in day traps) again exhibited the typical bimodal activity pattern observed in the past (Fig. 13): a pronounced peak in the spring due to ovipositing females and, to a lesser extent, deutonymphs; and a less distinct mid-summer peak due mainly to larvae in search of insect hosts. Total weekly catches of T. auroraense were again tightly correlated between sites in 1989 (Fig. 13).

#### 3.2. Abrolophus sp.

Unlike T. auroraense, Abrolophus appears to overwinter in the egg stage. Larvae are active in May and June, and deutonymphs June through August. Adult numbers peak in August, and disappear completely by late September. Total numbers trapped (all stages lumped) were significantly correlated between sites (Fig. 14), with adults alone being particularly well

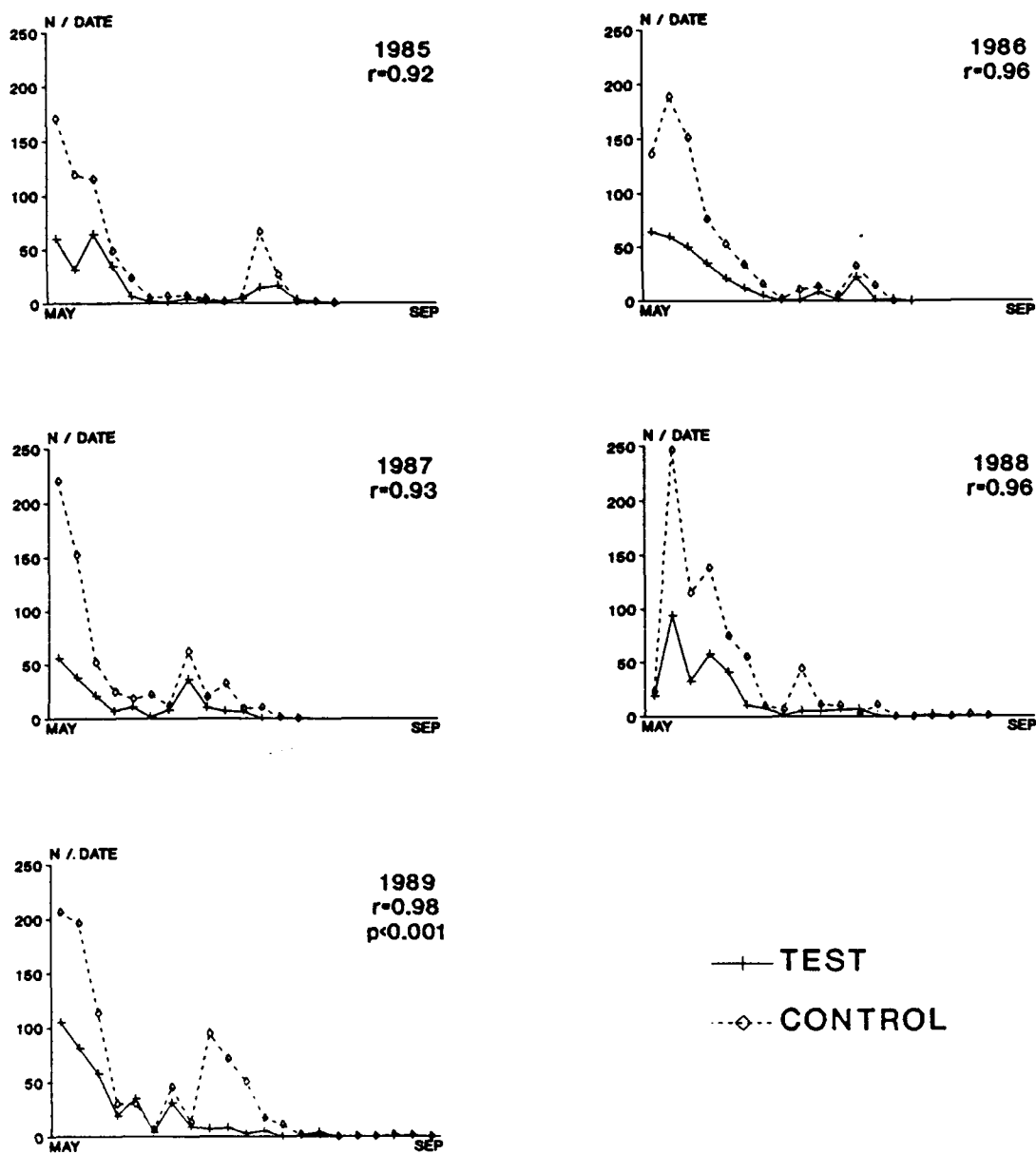


Fig. 13. Weekly captures of *Trombidium auroraense* in Test and Control, 1985 to 1989.

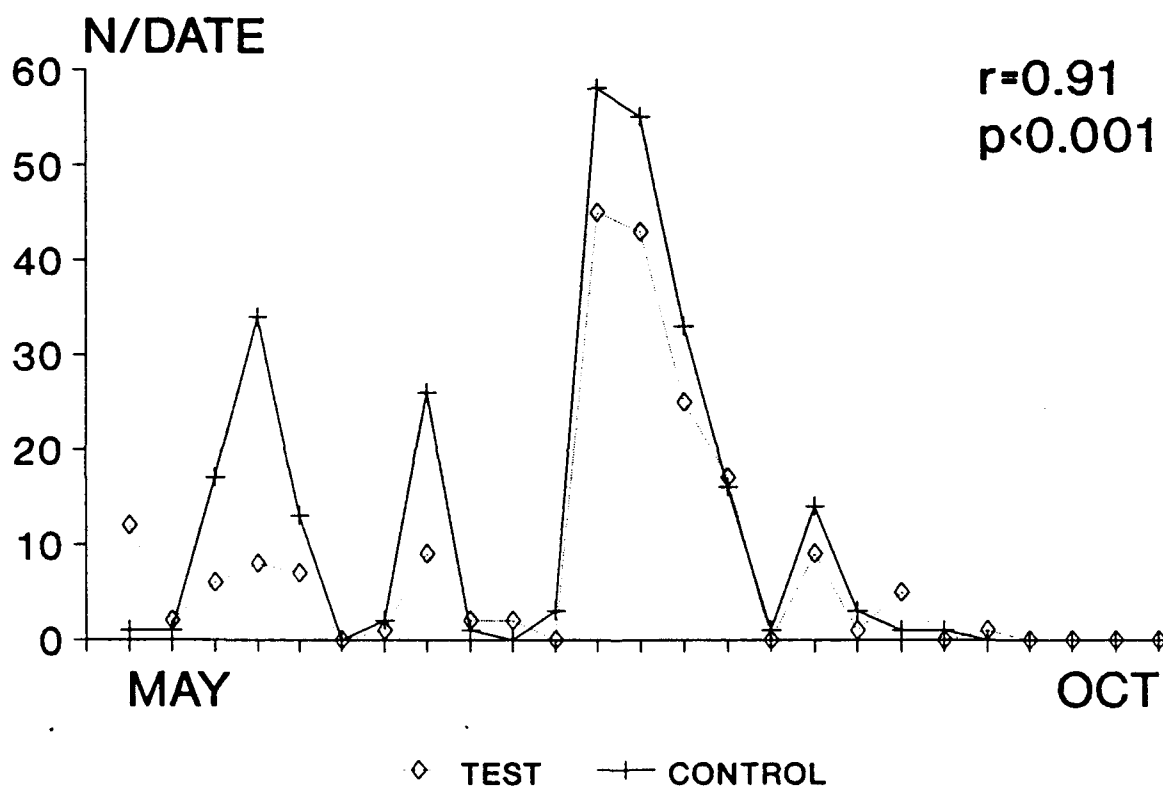
*Abrolophus* sp.

Fig. 14. Weekly trap catches of Abrolophus sp. in Test and Control, 1989.

synchronized ( $r = 0.97$ ,  $P < 0.001$ ).

Bi-weekly (2 dates summed) frequency distributions among the three active developmental stages (protonymphs and tritonymphs of velvet mites are calyptostatic) are illustrated in Fig. 15. Although Anova disclosed site effects for nymphs and adults which were significant, we reserve judgment until past years' data have been re-checked, so that interactions involving sites, dates and years can be evaluated.

### 3.3. Nanorchestes sp. A

In the Test site, but again not in Control, numbers trapped and mean annual abundance /m<sup>2</sup> have remained correlated through 1989 ( $r = 0.98$ ,  $P < 0.01$ ) (Table 14).

Table 14. Annual mean density (litter + soil) and total number of Nanorchestes trapped in 1985 to 1989.

|                   | 1985 | 1986 | 1987 | 1988 | 1989 |
|-------------------|------|------|------|------|------|
| TEST              |      |      |      |      |      |
| N/ m <sup>2</sup> | 119  | 1163 | 401  | 344  | 273  |
| N trapped         | 1322 | 4405 | 1746 | 2216 | 1810 |
| CONTROL           |      |      |      |      |      |
| N/ m <sup>2</sup> | 266  | 771  | 186  | 227  | 246  |
| N trapped         | 808  | 5926 | 2329 | 4984 | 2697 |

Fluctuations in weekly captures of Nanorchestes (Fig. 16) were well synchronized between sites in 1989, activity peaks in the summer months being comparable to those observed in the past.

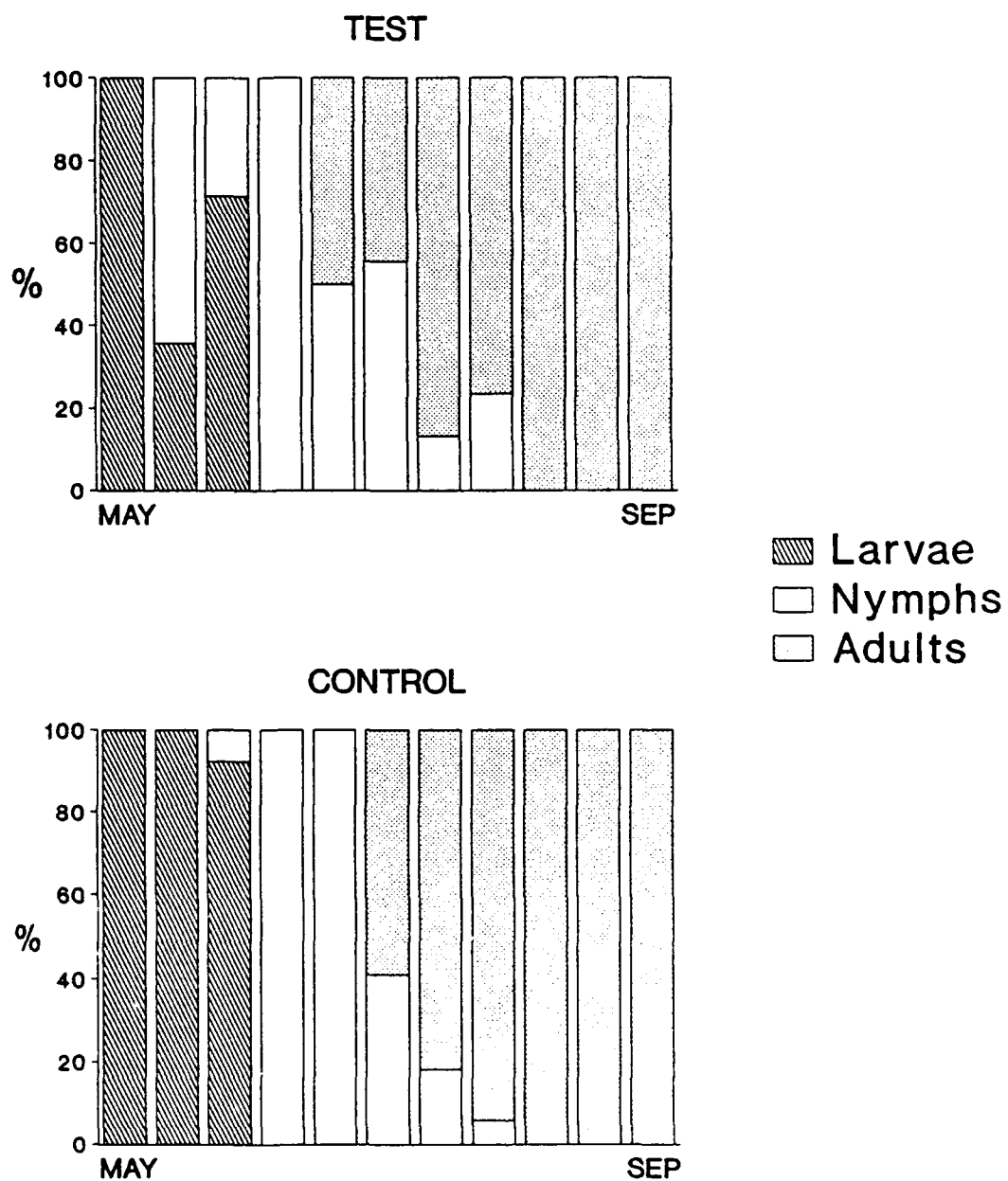


Fig. 15. Bi-weekly frequencies of developmental stages of Abrolophus sp. in Test and Control, 1989.

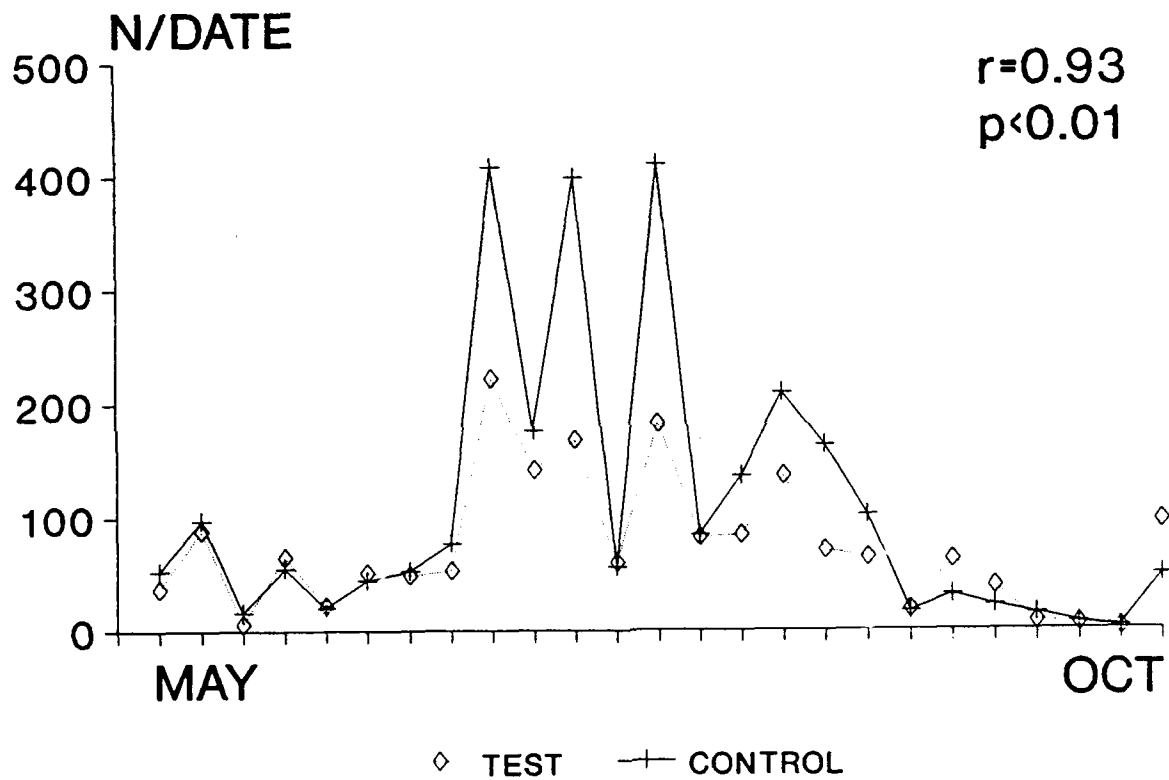
*Nanorchestes* sp. A

Fig. 16. Weekly trap catches of Nanorchestes sp. A in Test and Control, 1989.

#### 4. Carabid beetles

Because 1989 identifications are incomplete, we defer discussion of carabid diel and seasonal activity patterns until later. However, we have recently augmented the data base concerning carabid fecundity, which currently encompasses four species and four years (1985-88, sect. 4.2. and 4.3.). In the following, a few descriptive summaries are presented, to add to past years' data bases.

##### 4.1. Sex ratios

An updated summary in Table 15 provides background information on sex ratios in addition to total numbers trapped, for the most common species in one or both sites. Although there is a tendency for males to be captured more frequently than females, there seem to be interesting modifying trends:

a. within Test, P. melanarius sex ratios decrease with increasing total numbers caught;

b. Synuchus impunctatus sex ratios are consistently lower in Control, where the species is trapped in much larger numbers than in Test, an apparent analogy to a.) above;

c. the obverse is true for P. pensylvanicus, in which males are slightly more frequent in the site where the species is more common;

d. in two spring breeders, P. pensylvanicus and C. frigidum, sex ratios were much lower in 1988 than in previous years. There may be a connection here between emergence from hibernation and very early (February-April) temperatures, which were lower in 1988 than in previous years. Since we do not monitor air and soil temperatures prior to May 1, we have yet to obtain the appropriate environmental data to explore this link further.



Table 15. Sex ratios [ (N males / N total) x 100] of common carabids in Test and Control.  
In parentheses: total number captured.

|                         | 1985           |               | 1986           |               | 1987          |               | 1988           |               |
|-------------------------|----------------|---------------|----------------|---------------|---------------|---------------|----------------|---------------|
|                         | T              | C             | T              | C             | T             | C             | T              | C             |
| <u>P. melanarius</u>    | 65.6<br>(1094) | 73.1<br>(186) | 59.7<br>(1170) | 70.9<br>(227) | 71.7<br>(643) | 79.5<br>(351) | 57.6<br>(1534) | 66.7<br>(309) |
| <u>P. pensylvanicus</u> | 60.7<br>(206)  | 55.0<br>(278) | 59.2<br>(179)  | 70.4<br>(247) | 56.9<br>(102) | 69.9<br>(176) | 36.5<br>(74)   | 43.8<br>(130) |
| <u>S. impunctatus</u>   | 81.6<br>(103)  | 46.4<br>(700) | 69.0<br>(261)  | 49.9<br>(894) | 73.1<br>(104) | 48.8<br>(367) | 52.7<br>(74)   | 43.9<br>(157) |
| <u>P. mutus</u>         | 56.5<br>(232)  | -             | 58.3<br>(204)  | -             | 42.3<br>(212) | -             | 57.3<br>(96)   | -             |
| <u>C. frigidum</u>      | 73.1<br>(67)   | 79.3<br>(29)  | 73.2<br>(149)  | 74.8<br>(111) | 86.4<br>(428) | 82.8<br>(198) | 43.5<br>(131)  | 46.4<br>(28)  |
| <u>H. fuliginosus</u>   | 48.7<br>(76)   | 69.1<br>(55)  | 49.6<br>(139)  | 63.8<br>(116) | 52.1<br>(71)  | 50.8<br>(61)  | 55.9<br>(127)  | 52.3<br>(88)  |

#### 4.2. Fecundity

Available data concern three spring-breeding and one summer-breeding species. We intend to increase the data base to include Synuchus impunctatus, a second summer breeder which will allow Test / Control comparison.

Average fecundity (sensu lato) for four species is given in Table 16. For P. mutus, common only in Test, we have data for three pre-operational years, with no significant differences between them in terms of the mean number of ripe ova carried by females. Within-year differences between sites are also not significant for P. melanarius and P. pensylvanicus. Given that seasonal trap catches (and thus the relative number of females captured during the time of maximum gravidity) vary between years, comparisons within each year are likely to be the most meaningful.

In Calosoma frigidum, we encountered a puzzling phenomenon, for which we have found no analogies in the pertinent literature. In 1985, 1986 and 1987, 90 to 100 percent of all trapped females were gravid. In 1988, out of a total of 85 specimens, only one carried 12 ripe ova (Table 16). All others possessed healthy, non-distended ovaries showing no signs of imminent development.

A small number of teneral females were also captured at the beginning of the 1988 activity cycle, which occurred 1 to 2 weeks later than in previous years. The anomaly was observed in both sites, and may be related to delayed emergence of adults from hibernation. Average monthly temperatures from January through April were well below means of the preceding years\*).

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\*) Data taken from Annual Report for 1988, tasks 5.13 / 5.14, page 19, Fig. 1.4.

Table 16. Mean number of ripe ova carried by carabid females in Test and Control; means  $\pm$  SD and range; N females in parentheses.

|                         |    | 1985                               | 1986                               | 1987                              | 1988                             |
|-------------------------|----|------------------------------------|------------------------------------|-----------------------------------|----------------------------------|
| <u>P. mutus</u>         | T: | 17.0 $\pm$ 5.6<br>6 - 36<br>(56)   | (NA)*                              | 15.6 $\pm$ 5.0<br>3 - 27<br>(67)  | 16.3 $\pm$ 8.2<br>1 - 42<br>(37) |
| <u>P. melanarius</u>    | T: | 14.2 $\pm$ 10.9<br>1 - 55<br>(141) | 13.5 $\pm$ 19.9<br>1 - 40<br>(219) | 12.7 $\pm$ 9.1<br>1 - 41<br>(138) | 9.7 $\pm$ 7.1<br>1 - 35<br>(284) |
|                         | C: | 14.8 $\pm$ 8.9<br>3 - 42<br>(30)   | 13.8 $\pm$ 10.9<br>1 - 33<br>(47)  | 11.5 $\pm$ 10.2<br>1 - 57<br>(71) | 10.3 $\pm$ 7.5<br>2 - 42<br>(64) |
| <u>P. pensylvanicus</u> | T: | 12.6 $\pm$ 4.5<br>1 - 23<br>(67)   | 11.6 $\pm$ 5.3<br>1 - 24<br>(59)   | 11.5 $\pm$ 3.9<br>5 - 18<br>(38)  | 10.0 $\pm$ 4.2<br>3 - 20<br>(36) |
|                         | C: | 11.7 $\pm$ 4.1<br>2 - 22<br>(93)   | 10.0 $\pm$ 4.6<br>3 - 19<br>(49)   | 11.0 $\pm$ 4.3<br>3 - 22<br>(52)  | 9.2 $\pm$ 4.9<br>2 - 26<br>(47)  |
| <u>C. frigidum</u>      | T: | 13.9 $\pm$ 8.0<br>3 - 35<br>(17)   | 15.9 $\pm$ 7.4<br>4 - 34<br>(29)   | 17.6 $\pm$ 6.1<br>4 - 30<br>(43)  | (12.0)<br>-<br>(1)**             |
|                         | C: | 15.8 $\pm$ 10.2<br>3 - 31<br>(6)   | 16.3 $\pm$ 6.0<br>6 - 31<br>(27)   | 17.3 $\pm$ 6.1<br>4 - 28<br>(27)  | 0.0<br>-<br>(0)**                |

\* (NA): most specimens were accidentally dessicated, not available.

\*\* : 71 Test females and 14 Control females actually dissected.

If we postulate that vitellogenesis is triggered by exposure of females to short- followed by long-day periods in very early spring, then the necessary synchronicity between emergence from hibernation and photoperiodic events could have been "missed" in 1988. We know that the 1989 material contains only a few isolated specimens of C. frigidum, and suggest that a small proportion of the population lives for two years and thus saves it from virtual extinction due to unusual climatic events.

#### 4.3. Developmental patterns

We have shown in earlier reports that the seasonal activity cycles of several species are well correlated between sites, and are in general agreement between years as well. Dissections of females allow further data examination with respect to patterns of ovarian development and recruitment and growth cycles.

Since we have not previously shown these data, we will illustrate and describe these patterns below. Statistical treatment (where numbers of gravid females captured are adequate) is currently confined to correlations between sites.

We can distinguish five stages in the female cycle:

1. Teneral (T) : integument not fully hardened, small ovaries.
2. Well developed (W): ovaries distended, egg maturation under way.
3. Gravid (GM): mature ova present, ovaries still containing more, as yet undeveloped eggs.
4. Gravid-Spent (GS): some mature ova still present, no additional eggs to be developed.
5. Spent (S): no more ova present.

Of these five types, gravid females are by far the most active, and are thus caught in largest numbers. Well-developed (W) individuals of P. mutus, P. pensylvanicus and C. frigidum are essentially absent from pit-traps, but are occasionally well represented in catches of P. melanarius. Teneral and spent females are rarely very active, and yield greatly variable numbers from year to year.

All five types of females can be used descriptively to characterize the developmental cycle of a species. For analysis between years or sites, however, we depend on gravid females due to their numerical dominance.

Gravid females of Calosoma frigidum (Fig. 17: 1985 not included because of very low captures in Control) begin appearing in the second week of May. Activity peaks in late May or early June, occasional GS or S individuals are caught toward and after the end of the breeding season. A single teneral female was trapped in the first week of May in 1987. Correlation coefficients for [GM + GS] females can be low in some years due to low numbers and brief activity periods (e.g.,  $r = 0.66$  and  $P < 0.1$  in 1987). In general, the species overwinters as adults with, rarely, larvae surviving the winter and metamorphosing in early spring.

The 1988 anomaly discussed earlier is clearly evident in Fig. 17. The synchronicity of the species' delayed appearance in Test and Control is evidenced by a coefficient of 0.92 ( $P < 0.001$ ).

Pterostichus mutus, common only in Test, is also spring-breeding (Fig. 18). Gravid females are present throughout May, activity declining rapidly toward the first week of June. GS and S females are captured during the subsequent 2 to 4 weeks. Teneral adults are active in September and October, and overwinter to begin the cycle again the following spring.

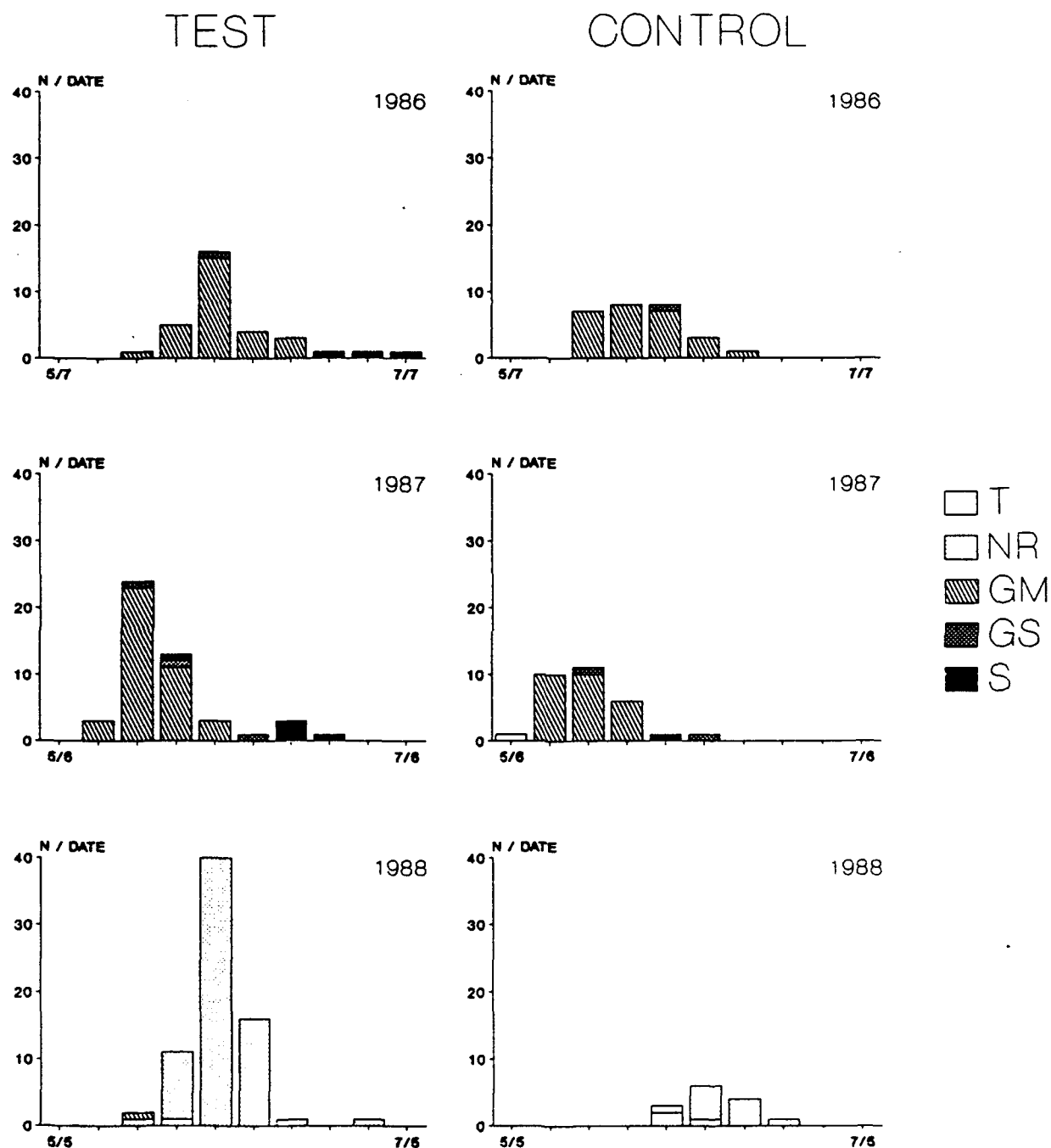


Fig. 17. The reproductive cycle of *Calosoma frigidum* in Test and Control, 1986 to 1988. For explanation of symbols see text, p. 54.

Note: NR = non-reproductive.

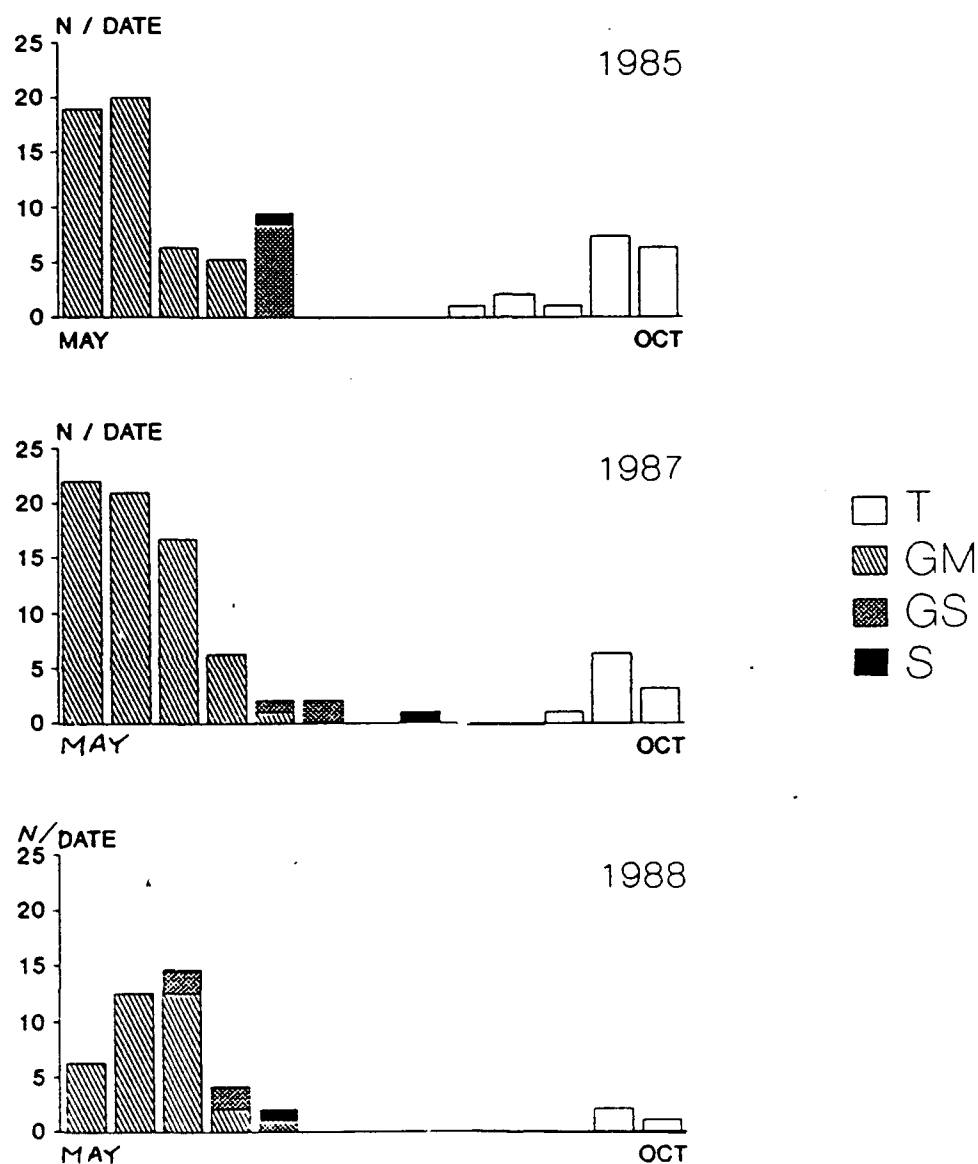


Fig. 18. The breeding cycle of *Pterostichus mutus* in Test (1986 specimens not available). For explanation of symbols see text p. 54.

The annual cycle of P. pensylvanicus (Fig. 19) is closely similar to that of P. mutus (Fig. 18), although the late-season presence of spent females indicates that a small proportion overwinters and breeds a second time the following year. Correlations between sites are generally significant at  $P < 0.05$  or better,  $r$  ranging from 0.78 (1986) to 0.91 (1985) for the first 14 fortnights of each season.

The developmental cycle of P. melanarius is slightly more complex. We first illustrate it by means of a single year and site (Test 1985) in order to delineate the basic pattern (Fig. 20). The main influx of teneral adults in July furnishes the bulk of the year's reproductive females in July and August; GS and S females accompany and follow them, the last spent females being active into October. A small proportion of the population overwinters as adults and appears in May and June as the first W and GM females of the year. Indeed, the May and June reproductive effort leads to the few tenerals captured in late October (Fig. 20). Although essentially a summer-autumn breeder, P. melanarius is thus more plastic than other species, exhibiting a secondary spring oviposition cycle in addition to the main summer peak.

We selected 1988 as example of between-site comparison (Fig. 21). In order to simplify the illustration, W females are omitted, and [GM + GS] individuals are lumped. For all four years, correlations between the number of gravid females captured per fortnight are significant at  $P < 0.01$  or better, with  $r$  ranging from 0.73 (1987) to 0.90 (1988).

If total numbers trapped remain reasonably high in both sites, single-year tests should furnish simple evidence of potential disturbance.



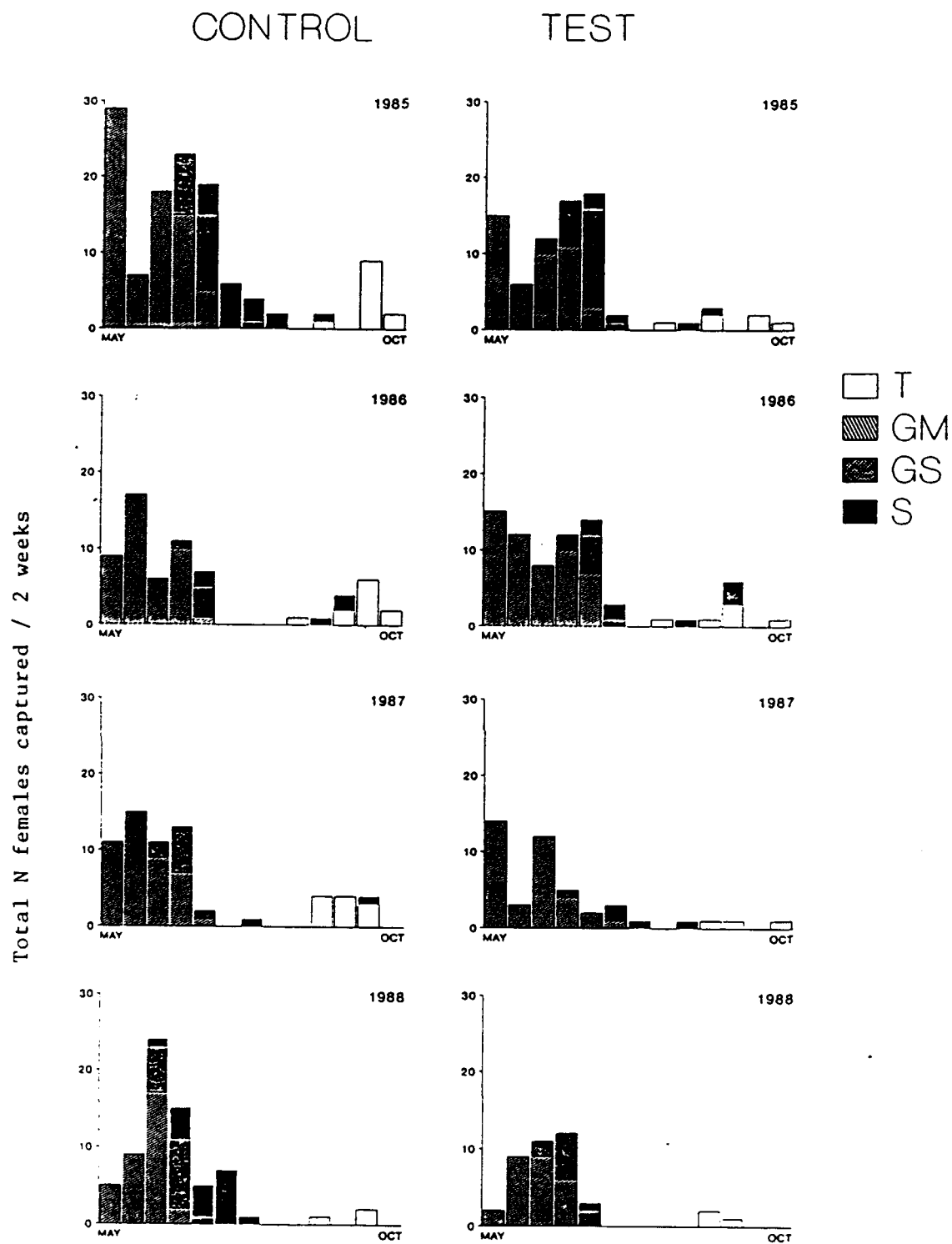


Fig. 19. The developmental cycle of Pterostichus pensylvanicus in Test and Control, 1985 to 1988. For explanation of symbols see text p. 54.

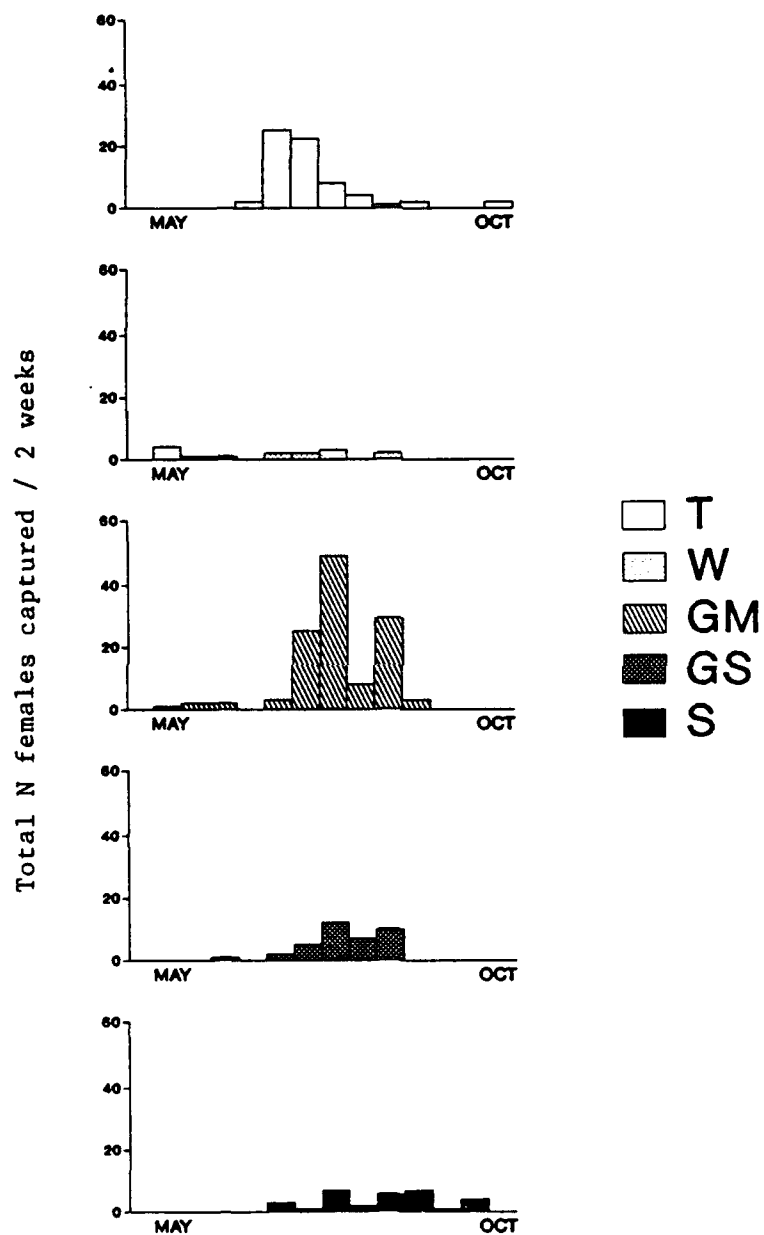


Fig. 20. The breeding cycle of *Pterostichus melanarius*, Test site, 1985.  
For explanation of symbols see text p. 54.

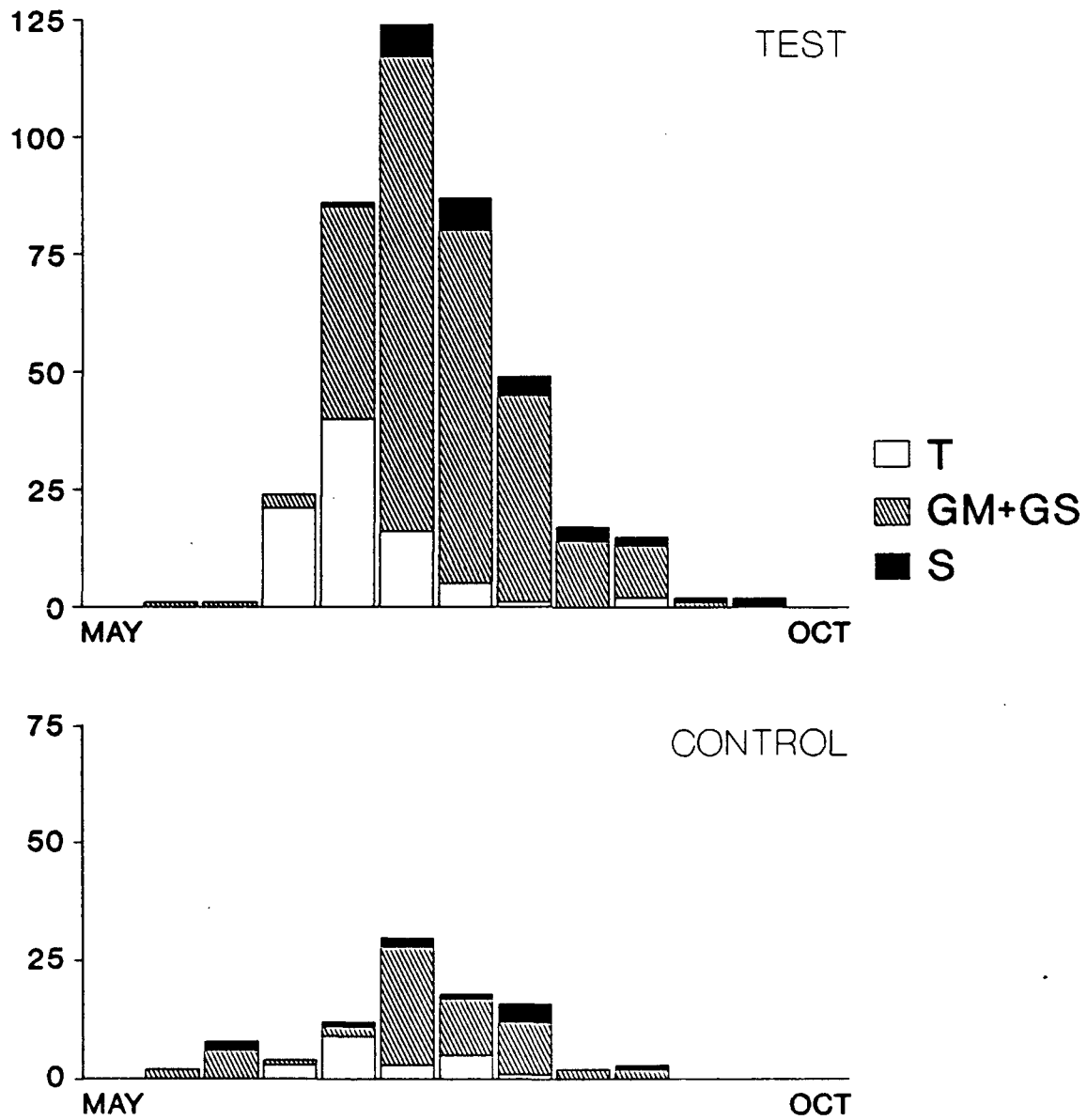


Fig. 21. The breeding cycle of *P. melanarius* in 1988, Test and Control: total numbers of each female type captured / two weeks. For explanation of symbols, see text p. 54.



## V. EARTHWORMS

In 1990, we continued to sample lumbricids at intervals of 2 weeks, to a depth of 30 cm below the lower A horizon boundary, from May 7 to October 22. All earthworms and cocoons have been identified and weighed, and the most relevant initial data analyses have been completed. For the purpose of this report, the species chosen for detailed discussion include only those which allow conclusions regarding potential ELF effects.

### 1. Statistical approach

Selected descriptive data summaries are provided to aid recall of general species-specific patterns of reproduction, growth and abundance. Where appropriate, standard deviations or confidence limits are listed to support our interpretation of results.

The main statistical tools are correlation and linear regression. Plotting of confidence limits for slopes, or confidence limits of estimated Y variables, form the basis for conclusions. For earthworms, we considered it prudent to treat 1989 as well as 1990 as operational years, letting the data themselves judge whether a potential ELF effect occurred. We thus use the five pre-ELF years of 1984 to 1988 as background data from which predicted estimates (regression) or comparisons to confidence limits (correlation) are derived.

Our rationale for choosing specific dependent and independent variables is discussed in the appropriate places, and data manipulations, where necessary, are described.

## 2. Species composition and abundance

We reported last year that seven of the eight species we deal with are shared between sites, although a given species may be dominant in one site and rare in the other. Since then, we have added yet another taxon to the list of those rare in both sites: Octolasion tyrtaeum (Savigny), the presence of which was evidenced in 1990 by a few scattered cocoons. These are green and translucent and differ clearly from those of all other species. We confirmed their identity by rearing a single clitellate individual recovered from just outside the periphery of the Control site.

We have also established criteria for distinguishing immatures of the Test Aporrectodea spp. We reported earlier that the relatively rare trapezoides was difficult to distinguish from longa. After examining a large series of trapezoides stemming from Control (where the species is abundant), we have re-checked all pertinent Test material, separating trapezoides and longa immatures. Although there is likely to be some error (both forms are pigmented), we believe the data are now reasonably correct estimates for all Test species.

Based on corrected data, yearly abundances of all species are summarized in Table 17, and we briefly discuss 1990 data in perspective to earlier years. Among Test species, Lumbricus rubellus experienced a significant density increase; we predicted such an increase last year, given high cocoon production in 1989 and propitious moisture conditions in 1990. The rare Aporrectodea trapezoides continued the upward trend noted in 1989, reaching highest abundance in 1990. For the first time in seven years, we finally obtained one adult Lumbricus terrestris from Test samples (only cocoons had been found previously).

Table 17. Mean annual abundance /m<sup>2</sup> ± 95% CL of lumbricid species in Test and Control sites. Numbers in parentheses: abundance to a depth of 20 cm below the A horizon, allowing comparison with 1984 and 1985 data, years in which the 20-30 cm layer was not sampled. "Sample" = sum of all vertical layers.

| YEAR                    | 1984       | 1985       | 1986                | 1987                | 1988                | 1989                | 1990                |
|-------------------------|------------|------------|---------------------|---------------------|---------------------|---------------------|---------------------|
| N sam./yr/site          | 120        | 156        | 156                 | 102                 | 120                 | 130                 | 130                 |
| TEST:                   |            |            |                     |                     |                     |                     |                     |
| <u>D. octaedra</u>      | 36 ± 9.7   | 56 ± 13.5  | 61 ± 10.5           | 63 ± 12.9           | 39 ± 8.6            | 26 ± 5.7            | 34 ± 7.0            |
| <u>L. rubellus</u>      | 68 ± 7.5   | 85 ± 7.9   | 83 ± 7.5            | 91 ± 10.9           | 66 ± 8.7            | 71 ± 7.7            | 130 ± 10.6          |
| <u>A. tuberculata</u>   | 252 ± 20.5 | 304 ± 24.1 | 278 ± 16.9<br>(267) | 290 ± 25.8<br>(282) | 327 ± 25.8<br>(315) | 295 ± 22.8<br>(283) | 335 ± 28.3<br>(328) |
| <u>A. longa</u>         | 27 ± 4.2   | 25 ± 3.7   | 29 ± 4.2<br>(28)    | 28 ± 4.6<br>(26)    | 28 ± 4.4<br>(28)    | 25 ± 4.5<br>(25)    | 32 ± 5.3<br>(31)    |
| <u>A. trapezoides</u>   | 3.7        | 4.2        | 3.8                 | 3.6                 | 5.5                 | 6.4                 | 8.4                 |
| <u>A. turgida*</u>      | -          | 0.2        | 0.1                 | -                   | 0.7                 | 0.5                 | 0.1                 |
| <u>D. rubidus</u>       | 0.1        | -          | 0.1                 | -                   | 0.3                 | -                   | -                   |
| <u>L. terrestris</u>    | -          | -          | -                   | -                   | -                   | -                   | 0.1                 |
| CONTROL:                |            |            |                     |                     |                     |                     |                     |
| <u>D. octaedra</u>      | 180 ± 26.4 | 296 ± 35.9 | 171 ± 16.6          | 290 ± 50.3          | 103 ± 15.3          | 74 ± 9.9            | 197 ± 29.7          |
| <u>A. turgida</u>       | 209 ± 22.4 | 179 ± 16.5 | 162 ± 16.6<br>(155) | 136 ± 17.1<br>(133) | 195 ± 18.8<br>(190) | 172 ± 15.5<br>(168) | 265 ± 24.4<br>(262) |
| <u>A. trapezoides</u>   | 60 ± 7.9   | 56 ± 6.7   | 74 ± 7.0<br>(58)    | 96 ± 12.5<br>(82)   | 91 ± 10.1<br>(80)   | 117 ± 11.9<br>(105) | 121 ± 11.2<br>(110) |
| <u>A. tuberculata*</u>  | 0.1        | 0.3        | 1.6                 | 2.0                 | 3.5                 | 4.6                 | 6.5                 |
| <u>D. rubidus</u>       | 1.2        | 0.7        | 1.0                 | 2.2                 | 0.9                 | 0.2                 | 0.2                 |
| <u>Lumbricus spp.**</u> | 0.6        | 5.7        | 7.2                 | 8.7                 | 9.6                 | 12.3                | 9.6                 |

\* based on adults only; immatures of turgida and tuberculata are not distinguishable

\*\* combined estimate for L. terrestris and L. rubellus

The endogeics A. tuberculata (Test) and A. turgida (Control) reached peak abundance in 1990, significantly so for turgida (Table 17). Last year, we cautiously predicted such an increase, based on high influx of recruits in 1988 and reasonably high cocoon production in 1989. It is now clear that in species which are likely to live for several years, reproductive events in one year may not affect abundance until 2 years later. In contrast, the short-lived D. octaedra showed a significant numerical increase in 1990 (but only in Control): low abundance in 1989 was due mainly to the effects of the 1988 drought, high abundance in 1990 being attributable to high cocoon production in 1989. The same species has consistently shown density fluctuations of much lower amplitude in the Test site.

Finally, it is interesting that A. trapezoides in Control maintained its trend of increasing abundance, in parallel to its behavior in the Test site, where the species is relatively rare (Table 17).

### 3. Vertical distribution

The endogeics tuberculata and turgida, after a period of drought, occasionally show a delayed response to re-hydration of the A horizon. We attempted to improve regressions of (proportion of the population in A) on (% soil moisture) by using a phase shift, i.e., moving observed proportions forward by one or two dates. Although  $r^2$  was slightly improved in a few cases, regressions which had been not significant remained not significant. The behavioral response to increased moisture is thus relatively rapid (given point sampling at two week intervals), although the physiological response in terms of resumed reproduction usually is not (ref. section 5.1.2.).

The vertical distribution of tuberculata and turgida adults as a function



of moisture was quantified by regression analysis (Table 18).

Table 18. Results of regressing the proportion of adult tuberculata and turgida in the A horizon ( $\ln [p / (1-p)]$ ) on percent A horizon moisture.

|                     | df | r    | a     | b $\pm$ 95% CL    | P     |
|---------------------|----|------|-------|-------------------|-------|
| <u>tuberculata:</u> |    |      |       |                   |       |
| 1984                | 10 | 0.27 | 24.25 | 1.290 $\pm$ 0.679 | 0.403 |
| 1985                | 11 | 0.82 | 22.64 | 2.601 $\pm$ 0.375 | 0.000 |
| 1986                | 11 | 0.88 | 22.48 | 2.161 $\pm$ 0.320 | 0.000 |
| 1987                | 8  | 0.61 | 26.08 | 1.328 $\pm$ 0.647 | 0.058 |
| 1988                | 10 | 0.86 | 16.72 | 2.374 $\pm$ 0.359 | 0.000 |
| 1984- 88            | 58 | 0.65 | 22.13 | 2.106 $\pm$ 0.200 | 0.000 |
| 1989                | 11 | 0.19 | 23.53 | 0.393 $\pm$ 0.652 | 0.541 |
| 1990                | 11 | 0.67 | 23.22 | 1.867 $\pm$ 0.493 | 0.011 |
| <u>turgida:</u>     |    |      |       |                   |       |
| 1984                | 10 | 0.67 | 23.69 | 2.886 $\pm$ 0.522 | 0.015 |
| 1985                | 11 | 0.79 | 26.34 | 2.554 $\pm$ 0.407 | 0.001 |
| 1986                | 11 | 0.60 | 26.39 | 1.741 $\pm$ 0.533 | 0.030 |
| 1987                | 8  | 0.55 | 23.83 | 2.685 $\pm$ 0.683 | 0.099 |
| 1988                | 10 | 0.74 | 21.33 | 2.448 $\pm$ 0.525 | 0.005 |
| 1984- 88            | 58 | 0.67 | 24.52 | 2.406 $\pm$ 0.195 | 0.000 |
| 1989                | 11 | 0.79 | 22.29 | 2.948 $\pm$ 0.405 | 0.001 |
| 1990                | 11 | 0.50 | 25.67 | 2.336 $\pm$ 0.574 | 0.079 |

Moisture generally explains a greater percentage of the variation encountered in tuberculata than it does in turgida. Non-significant relationships and low coefficients are tied to relatively moist years; especially in tuberculata, highest  $r$ 's are obtained in years with the greatest moisture deficits (1985, 86 and 88). 1990 regression slopes

were definitely not outlying, indicating that behavioral responses of tuberculata in terms of vertical distribution were likely to be unaffected by ELF operation.

We speculated last year that the lack of significance for L. rubellus response to litter moisture in 1989 (Table 19) was due to relatively low proportions of small immatures in the population. Small immatures were abundant in 1990 (section 6.1.), and an  $r$  of 0.74 ( $P < 0.004$ ) was obtained, with a regression slope well within the boundaries of pre-ELF years.

For epigeic species, 1990 was probably the year with the most favorable litter moisture conditions, rarely falling below 50% (Fig. 2). In both sites, regression coefficients for D. octaedra were low (Table 20), indicating that litter moisture above a critical level (which may well be around 50%) is not a discriminant factor for vertical distribution. Again, it seems likely that EM fields did not affect behavioral responses to moisture.

Table 19. Results of regressing the proportion of L. rubellus in leaf litter on litter moisture (Test site). Transformations:  $\ln$  (% moisture) and  $\ln [p / (1-p)]$ .

|         | df | r    | a      | b $\pm$ 95% CL    | P     |
|---------|----|------|--------|-------------------|-------|
| 1984    | 10 | 0.79 | -6.922 | 1.197 $\pm$ 0.429 | 0.002 |
| 1985    | 11 | 0.67 | -5.695 | 0.848 $\pm$ 0.494 | 0.012 |
| 1986    | 11 | 0.80 | -7.284 | 1.269 $\pm$ 0.401 | 0.001 |
| 1987    | 8  | 0.96 | -7.738 | 1.483 $\pm$ 0.223 | 0.000 |
| 1988    | 10 | 0.39 | -5.43  | 1.010 $\pm$ 0.649 | 0.208 |
| 1984-88 | 58 | 0.67 | -6.612 | 1.161 $\pm$ 0.195 | 0.000 |
| 1989    | 11 | 0.28 | -3.949 | 0.410 $\pm$ 0.638 | 0.358 |
| 1990    | 11 | 0.74 | -8.356 | 1.481 $\pm$ 0.449 | 0.004 |

Table 20. Results of regressing the proportion of the D. octaedra population in leaf litter on litter moisture. Transformations:  $\ln (\% \text{ moisture})$  and  $\ln [p / (1-p)]$ .

|               | df | r    | a       | b $\pm$ 95% CL    | P     |
|---------------|----|------|---------|-------------------|-------|
| CONTROL: 1984 | 10 | 0.88 | -7.456  | 1.804 $\pm$ 0.341 | 0.000 |
| 1985          | 11 | 0.71 | -4.407  | 0.946 $\pm$ 0.464 | 0.006 |
| 1986          | 11 | 0.95 | -10.317 | 2.293 $\pm$ 0.203 | 0.000 |
| 1987          | 8  | 0.85 | -12.603 | 3.046 $\pm$ 0.426 | 0.002 |
| 1988          | 10 | 0.80 | -10.713 | 2.527 $\pm$ 0.422 | 0.001 |
| 1984- 88      | 58 | 0.81 | -8.922  | 2.069 $\pm$ 0.152 | 0.000 |
| 1989          | 11 | 0.69 | -8.547  | 1.755 $\pm$ 0.526 | 0.027 |
| 1990          | 11 | 0.47 | -5.091  | 1.414 $\pm$ 0.585 | 0.104 |
| TEST: 1984    | 10 | 0.86 | -6.502  | 1.506 $\pm$ 0.356 | 0.000 |
| 1985          | 11 | 0.71 | -4.628  | 1.143 $\pm$ 0.469 | 0.007 |
| 1986          | 11 | 0.88 | -8.270  | 1.850 $\pm$ 0.309 | 0.000 |
| 1987          | 8  | 0.90 | -5.628  | 1.364 $\pm$ 0.363 | 0.000 |
| 1988          | 10 | 0.76 | -7.221  | 1.722 $\pm$ 0.455 | 0.003 |
| 1984- 88      | 58 | 0.80 | -6.503  | 1.527 $\pm$ 0.157 | 0.000 |
| 1989          | 11 | 0.66 | -5.167  | 1.067 $\pm$ 0.500 | 0.013 |
| 1990          | 11 | 0.55 | -4.257  | 1.094 $\pm$ 0.556 | 0.051 |

#### 4. Cocoon weights

Table 21 allows us to review annual fluctuations in the mean mass of cocoons, and to compare 1990 with previous years. Species-specific cocoon size or mass is relatively constant between years. Given the generally high replication, small differences can prove significant: in A. tuberculata, mean cocoon mass in the driest years (1985, 86 and 88) was significantly lower than in 1984, 1987 or 1990 (two-sample t tests,  $P < 0.02$  or lower).

Table 21. Mean mass ( $\pm$  SD), in mg, of new cocoons of Test and Control lumbricids; N cocoons weighed in parentheses.

|                      | 1984                      | 1985                      | 1986                      | 1987                      | 1988                      | 1989                      | 1990                      |
|----------------------|---------------------------|---------------------------|---------------------------|---------------------------|---------------------------|---------------------------|---------------------------|
| <u>octaedra</u> T    | 3.48 $\pm$ 0.46<br>(307)  | 3.52 $\pm$ 0.50<br>(180)  | 3.44 $\pm$ 0.49<br>(241)  | 3.39 $\pm$ 0.49<br>(263)  | 3.41 $\pm$ 0.35<br>(101)  | 3.41 $\pm$ 0.48<br>(205)  | 3.26 $\pm$ 0.42<br>(155)  |
| <u>octaedra</u> C    | 3.55 $\pm$ 0.48<br>(772)  | 3.53 $\pm$ 0.48<br>(717)  | 3.48 $\pm$ 0.43<br>(673)  | 3.39 $\pm$ 0.44<br>(634)  | 3.32 $\pm$ 0.46<br>(516)  | 3.44 $\pm$ 0.52<br>(798)  | 3.37 $\pm$ 0.46<br>(689)  |
| <u>rubellus</u> T    | 9.40 $\pm$ 1.64<br>(322)  | 9.49 $\pm$ 1.62<br>(400)  | 9.43 $\pm$ 1.67<br>(460)  | 8.91 $\pm$ 1.64<br>(405)  | 9.09 $\pm$ 1.61<br>(232)  | 9.72 $\pm$ 1.80<br>(600)  | 9.51 $\pm$ 1.71<br>(508)  |
| <u>tuberculata</u> T | 21.36 $\pm$ 3.74<br>(186) | 19.59 $\pm$ 4.17<br>(137) | 19.36 $\pm$ 4.94<br>(44)  | 20.73 $\pm$ 4.08<br>(223) | 18.69 $\pm$ 4.01<br>(63)  | 20.36 $\pm$ 3.64<br>(174) | 21.26 $\pm$ 4.09<br>(56)  |
| <u>longa</u> T       | 37.94 $\pm$ 4.51<br>(18)  | 47.86 $\pm$ 7.65<br>(14)  | 42.83 $\pm$ 8.19<br>(11)  | 42.73 $\pm$ 7.85<br>(13)  | 37.21 $\pm$ 6.28<br>(11)  | 39.85 $\pm$ 6.42<br>(46)  | 41.04 $\pm$ 6.82<br>(18)  |
| <u>turgida</u> C     | 11.79 $\pm$ 1.77<br>(174) | 11.90 $\pm$ 1.93<br>(181) | 12.07 $\pm$ 1.79<br>(129) | 11.36 $\pm$ 2.08<br>(155) | 11.40 $\pm$ 1.94<br>(102) | 11.57 $\pm$ 1.85<br>(287) | 11.57 $\pm$ 1.91<br>(291) |
| <u>trapezoides</u> C | 24.91 $\pm$ 3.44<br>(160) | 24.79 $\pm$ 3.54<br>(125) | 24.65 $\pm$ 3.23<br>(79)  | 24.43 $\pm$ 3.50<br>(186) | 23.70 $\pm$ 4.13<br>(93)  | 25.22 $\pm$ 4.26<br>(509) | 23.58 $\pm$ 3.62<br>(247) |

## 5. Aporrectodea tuberculata

In 1989, we came to the conclusion that data on population structure are not suitable for rigorous comparisons between years although, descriptively, they are essential for following long-term trends. In particular, we estimate that the species takes 2 to 3 years to reach adulthood; thus the first fully operational year will not yield the tools for assessing the consequences of possible perturbation.

An immediate assessment of potential ELF effects is possible, however, with respect to the characteristics of reproduction.

The first basic relationship we quantify is the mean abundance of new cocoons, regressed on the mean density of clitellates (Fig. 22). The relationship is quite tight for the pre-ELF years, and neither 1989 nor 1990 deviate from their respective estimated values. In other words: given the number of clitellates present, the number of cocoons produced is in direct proportion to previous years. The question which remains is: should there have been more clitellates in 1990, given the environmental conditions during that year?

### 5.1. Choice of variables

#### 5.1.1. Independent variables

Among possible independent variables, A horizon moisture and temperature are the most relevant for endogeic lumbricids. In preliminary trials, neither temperature nor temperature/moisture combinations could be clearly related to reproductive parameters, and have tentatively been set aside. A horizon moisture proved to have predictive value, and was treated in the following way:

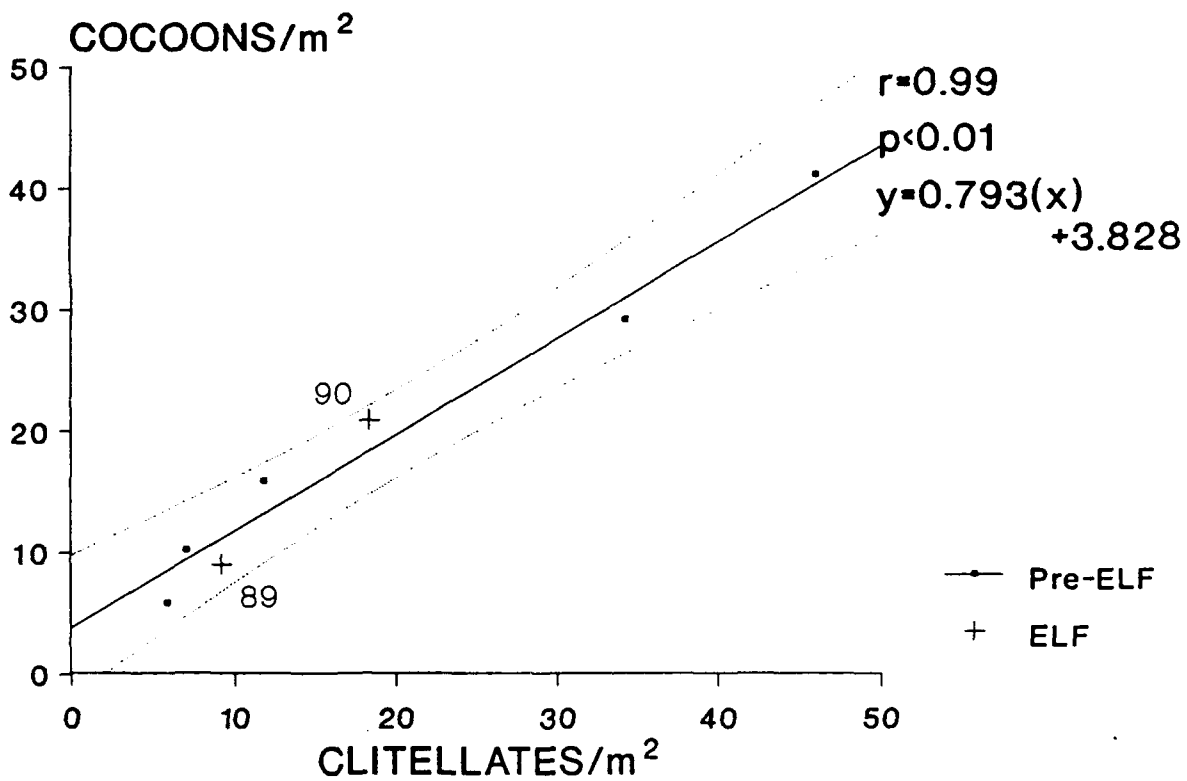


Fig. 22. Aporrectodea tuberculata: regression of mean annual new cocoons abundance on mean annual clitellate density (N= 5 pre-ELF years);

$$Y'_{89} = 18.4 \pm 3.61; \quad Y'_{90} = 11.1 \pm 4.41.$$

Ordinarily, the A horizon is the preferred habitat for tuberculata. Based on 1984-88 data, we estimated that "moisture stress" exists when  $\leq 60\%$  of the adults are present in the A horizon, the remainder having retreated to lower strata; this 60% threshold, though behavioral, generally coincides with or is immediately followed by changes in reproductive output. With  $N = 27$ ,  $r = 0.78$ ,  $P < 0.001$ , and  $y = 0.264x - 5.614$ , regression allowed us to predict the moisture level at which the 60% threshold would be reached, i.e., 23% moisture.

Data used to derive the equation: a) excluded date 1 of each year, because warm or cold springs introduce non-relevant variability; and b) included all subsequent dates up to the time when re-hydration occurred. Had we included later dates, the "delayed response effect" (see section 5.1.2.) would have distorted the data.

Deviations from 23% were then calculated for each date, and summed to obtain a single "deviation estimate" for each year.

#### 5.1.2. Dependent variables

After some preliminary analyses, the following three variables were chosen: mean abundance of new cocoons  $/m^2$ ;  
mean abundance of clitellates  $/m^2$ ;  
mean proportion of adults in the clitellate state.

Means were calculated for each date (10 or 12 samples per date) within each year. Dates 1 (variable temperature effects at the end of hibernation) and 13 (not available for all years) were excluded. Estimates for three dates in 1987 were obtained by interpolation between adjacent means: since we briefly switched from biweekly to monthly sampling in 1987, but biweekly soil moisture data consistently indicated "absence of potential stress", we felt that interpolation was justified.

Date-specific data for all years are listed in Table 22, including A horizon moisture and temperature, as well as the proportion of adults present in the A horizon.

Based on all 1984 through 1988 means, we then calculated pre-ELF means for the three parameters listed above. Given that these years spanned a wide variety of conditions, average reproductive characteristics yield a measure of "average species potential" typical for tuberculata. The resulting pre-ELF estimates were:

21.6 new cocoons /m<sup>2</sup>;

21.5 clitellates /m<sup>2</sup>;

0.261 proportion clitellate; N in each case = 55, three of them interpolated.

Deviations from these means were obtained for each date within each year by subtraction, and a single sum of deviations per year formed the final set of data for regression analysis (Table 23).

Table 23. Summed biweekly deviations from 1984-88 means of A. tuberculata reproductive parameters, and from 23% soil moisture.

|                      | 1984  | 1985   | 1986   | 1987  | 1988   | 1989  | 1990   |
|----------------------|-------|--------|--------|-------|--------|-------|--------|
| Moisture             | 26.7  | 15.7   | -13.5  | 47.2  | -46.9  | 5.1   | 29.2   |
| Coc /m <sup>2</sup>  | 84.0  | -62.8  | -173.5 | 276.0 | -125.6 | -7.2  | -138.4 |
| clit./m <sup>2</sup> | 139.5 | -107.2 | -172.5 | 288.3 | -159.7 | -34.9 | -135.7 |
| P clitell.           | 2.283 | -1.050 | -1.922 | 2.654 | -1.985 | 0.011 | -1.401 |

### 5.1.3. Analyses pending

Values in Table 23 represent annual estimates for the degree of "propitiousness" of soil moisture, and for average, species-specific "reproductive performance".



Table 22. Means per date (N = 10 or 12) pertinent for evaluating the reproductive performance of A. tuberculata in the Test site.

Note: °C of A horizon based on daily averages during the 2 weeks preceding each sampling occasion (no continuous records available for 1984).

| Year | Date | Clit./m <sup>2</sup> | P of ad. clitell. | Coc./m <sup>2</sup> | P of ad. in A hor. | % moist. A horiz. | mean °C A horiz. |
|------|------|----------------------|-------------------|---------------------|--------------------|-------------------|------------------|
| 84   | 2    | 16.0                 | .200              | 12.8                | .78                | 27.2              |                  |
| 84   | 3    | 4.8                  | .094              | 4.8                 | .88                | 23.4              |                  |
| 84   | 4    | 22.4                 | .241              | 11.2                | .88                | 24.2              |                  |
| 84   | 5    | 25.6                 | .308              | 22.4                | .79                | 25.2              |                  |
| 84   | 6    | 32.0                 | .444              | 24.0                | .60                | 25.6              |                  |
| 84   | 7    | 33.6                 | .553              | 32.0                | .58                | 16.6              |                  |
| 84   | 8    | 30.4                 | .422              | 19.2                | .64                | 23.3              |                  |
| 84   | 9    | 43.2                 | .600              | 27.2                | .71                | 29.0              |                  |
| 84   | 10   | 51.2                 | .800              | 49.6                | .95                | 25.7              |                  |
| 84   | 11   | 56.0                 | .761              | 57.6                | .70                | 30.7              |                  |
| 84   | 12   | 60.8                 | .731              | 60.8                | .71                | 28.8              |                  |
| 85   | 2    | 18.7                 | .264              | 34.7                | .89                | 26.2              | 12.2             |
| 85   | 3    | 13.3                 | .156              | 28.0                | .86                | 26.7              | 11.2             |
| 85   | 4    | 20.0                 | .246              | 18.7                | .67                | 22.6              | 12.0             |
| 85   | 5    | 24.0                 | .340              | 41.3                | .64                | 20.8              | 13.7             |
| 85   | 6    | 21.3                 | .348              | 25.3                | .10                | 18.9              | 15.6             |
| 85   | 7    | 4.0                  | .107              | 10.7                | .07                | 16.3              | 15.8             |
| 85   | 8    | 4.0                  | .063              | 2.7                 | .38                | 25.2              | 16.3             |
| 85   | 9    | .0                   | .000              | 2.7                 | .84                | 26.5              | 15.0             |
| 85   | 10   | 6.7                  | .093              | 2.7                 | .91                | 27.1              | 15.5             |
| 85   | 11   | 9.3                  | .097              | 4.0                 | .88                | 28.0              | 13.3             |
| 85   | 12   | 8.0                  | .107              | 4.0                 | .84                | 30.4              | 10.1             |
| 86   | 2    | 14.7                 | .186              | 16.0                | .85                | 24.0              | 11.3             |
| 86   | 3    | 4.0                  | .054              | 6.7                 | .32                | 17.2              | 11.9             |
| 86   | 4    | 8.0                  | .143              | 13.3                | .21                | 19.0              | 11.8             |
| 86   | 5    | 1.3                  | .024              | 9.3                 | .34                | 21.4              | 13.7             |
| 86   | 6    | 4.0                  | .071              | 2.7                 | .14                | 20.2              | 15.1             |
| 86   | 7    | .0                   | .000              | .0                  | .07                | 16.6              | 17.2             |
| 86   | 8    | 4.0                  | .058              | 2.7                 | .44                | 24.1              | 16.0             |
| 86   | 9    | .0                   | .000              | 2.7                 | .44                | 22.6              | 15.0             |
| 86   | 10   | 6.7                  | .088              | 4.0                 | .67                | 22.7              | 13.1             |
| 86   | 11   | 12.0                 | .200              | 4.0                 | .80                | 24.5              | 11.1             |
| 86   | 12   | 9.3                  | .125              | 2.7                 | .90                | 27.2              | 12.7             |
| 87   | 2    | 43.2                 | .443              | 24.0                | .77                | 30.0              | 10.8             |
| 87   | 3    | 49.6                 | .534              | 46.4                | .88                | 29.8              | 12.7             |
| 87   | 4    | 36.8                 | .500              | 38.4                | .89                | 27.7              | 14.3             |
| 87   | 5    | 17.6                 | .275              | 40.0                | .18                | 22.9              | 16.2             |
| 87   | 6    | 62.4                 | .582              | 65.6                | .61                | 26.3              | 16.3             |
| 87   | 7    | 38.4                 | .522              | 44.8                | .70                | 23.6              | 17.6             |
| 87   | 8    | 52.0                 | .575              | 54.4                | .75                | 26.0              | 17.4             |
| 87   | 9    | 65.6                 | .594              | 62.4                | .80                | 27.4              | 16.7             |
| 87   | 10   | 60.0                 | .531              | 56.0                | .73                | 28.4              | 14.3             |
| 87   | 11   | 54.4                 | .467              | 48.0                | .65                | 29.3              | 13.9             |
| 87   | 12   | 44.8                 | .502              | 33.6                | .60                | 28.8              | 11.9             |

Table 22 continued.

| Year | Date | Clit./m <sup>2</sup> | P of ad.<br>clitell. | Coc./m <sup>2</sup> | P of ad.<br>in A hor. | % moist.<br>A horiz. | mean °C<br>A horiz. |
|------|------|----------------------|----------------------|---------------------|-----------------------|----------------------|---------------------|
| 88   | 2    | 19.2                 | .158                 | 30.4                | .87                   | 20.8                 | 10.2                |
| 88   | 3    | 17.6                 | .207                 | 28.8                | .49                   | 16.1                 | 13.2                |
| 88   | 4    | 11.2                 | .096                 | 12.8                | .18                   | 15.1                 | 14.2                |
| 88   | 5    | .0                   | .000                 | 8.0                 | .05                   | 8.9                  | 14.4                |
| 88   | 6    | .0                   | .000                 | 3.2                 | .25                   | 18.9                 | 16.6                |
| 88   | 7    | .0                   | .000                 | 3.2                 | .39                   | 8.1                  | 16.9                |
| 88   | 8    | .0                   | .000                 | 12.8                | .89                   | 20.4                 | 18.5                |
| 88   | 9    | 1.6                  | .017                 | 3.2                 | .95                   | 22.4                 | 15.8                |
| 88   | 10   | 3.2                  | .050                 | 3.2                 | 1.00                  | 23.1                 | 13.8                |
| 88   | 11   | 11.2                 | .163                 | 3.2                 | .98                   | 28.6                 | 13.0                |
| 88   | 12   | 12.8                 | .195                 | 3.2                 | .78                   | 23.7                 | 9.8                 |
| 89   | 2    | 40.0                 | .555                 | 12.8                | .93                   | 25.3                 | 10.0                |
| 89   | 3    | 20.8                 | .309                 | 22.4                | .90                   | 25.9                 | 11.6                |
| 89   | 4    | 14.4                 | .300                 | 35.2                | .77                   | 27.4                 | 11.3                |
| 89   | 5    | 59.2                 | .725                 | 54.4                | .69                   | 24.7                 | 15.1                |
| 89   | 6    | 14.4                 | .265                 | 43.2                | .21                   | 22.9                 | 15.7                |
| 89   | 7    | 11.2                 | .226                 | 19.2                | .32                   | 21.9                 | 16.0                |
| 89   | 8    | 8.0                  | .094                 | 4.8                 | .79                   | 27.0                 | 16.1                |
| 89   | 9    | 4.8                  | .064                 | 6.4                 | .87                   | 20.0                 | 14.7                |
| 89   | 10   | 14.4                 | .173                 | 11.2                | .90                   | 21.1                 | 14.6                |
| 89   | 11   | 11.2                 | .127                 | 12.8                | .80                   | 21.4                 | 12.1                |
| 89   | 12   | 3.2                  | .044                 | 8.0                 | .60                   | 20.5                 | 8.8                 |
| 90   | 2    | 9.6                  | .095                 | 14.4                | .95                   | 28.2                 | 7.4                 |
| 90   | 3    | 3.2                  | .045                 | 6.4                 | .91                   | 28.0                 | 10.4                |
| 90   | 4    | 14.4                 | .132                 | 9.6                 | .96                   | 33.3                 | 12.6                |
| 90   | 5    | 6.4                  | .059                 | 14.4                | .74                   | 25.2                 | 14.2                |
| 90   | 6    | 12.8                 | .170                 | 11.2                | .62                   | 20.0                 | 14.4                |
| 90   | 7    | 9.6                  | .154                 | 6.4                 | .31                   | 25.2                 | 15.6                |
| 90   | 8    | 6.4                  | .129                 | 8.0                 | .29                   | 21.1                 | 14.0                |
| 90   | 9    | 9.6                  | .171                 | 11.2                | .85                   | 24.5                 | 15.3                |
| 90   | 10   | 9.6                  | .118                 | 1.6                 | .80                   | 23.7                 | 15.3                |
| 90   | 11   | 4.8                  | .107                 | 6.4                 | .71                   | 26.2                 | 12.0                |
| 90   | 12   | 14.4                 | .290                 | 9.6                 | .94                   | 26.8                 | 10.6                |

Preliminary examination of data had convinced us to use yearly estimates for analysis because seasonal (biweekly) data pose a problem which we have yet to solve. In general, when moisture decreases over two or more consecutive dates, tuberculata reproduction is curtailed. Recovery, however, is delayed and may not occur until two or three dates after re-hydration of the A horizon. Data for 1985 (Table 22, proportion clitellate vs. A horizon moisture) may serve as example. A given soil moisture level will thus be related to very different values of reproductive parameters, depending on the prior history of moisture fluctuations.

We are currently preparing data for further analysis based on monthly (means of 2 dates) or seasonal (means representing spring, summer and fall) estimates. The overall goal will be to arrive at multiple independent variables for each year and to derive confidence regions rather than intervals for given estimates of  $Y'$ .

## 5.2. Results

Using summed deviations (Table 23), regression of each of the reproductive parameters on soil moisture yields probabilities of  $P < 0.1$  for the pre-ELF years. Since these are field-derived estimates, we submit that this level of significance is acceptable for an initial evaluation of 1989 and 1990 values. By using 95% confidence limits, we believe our conclusions will be reasonably conservative.

For all three parameters tested, observed 1990 data were outside the estimated 95% confidence limits; 1989 data, however, coincided approximately with pre-ELF means in all cases (Figs. 23, 24 and 25).

Given that the predictor equations were derived from only five data

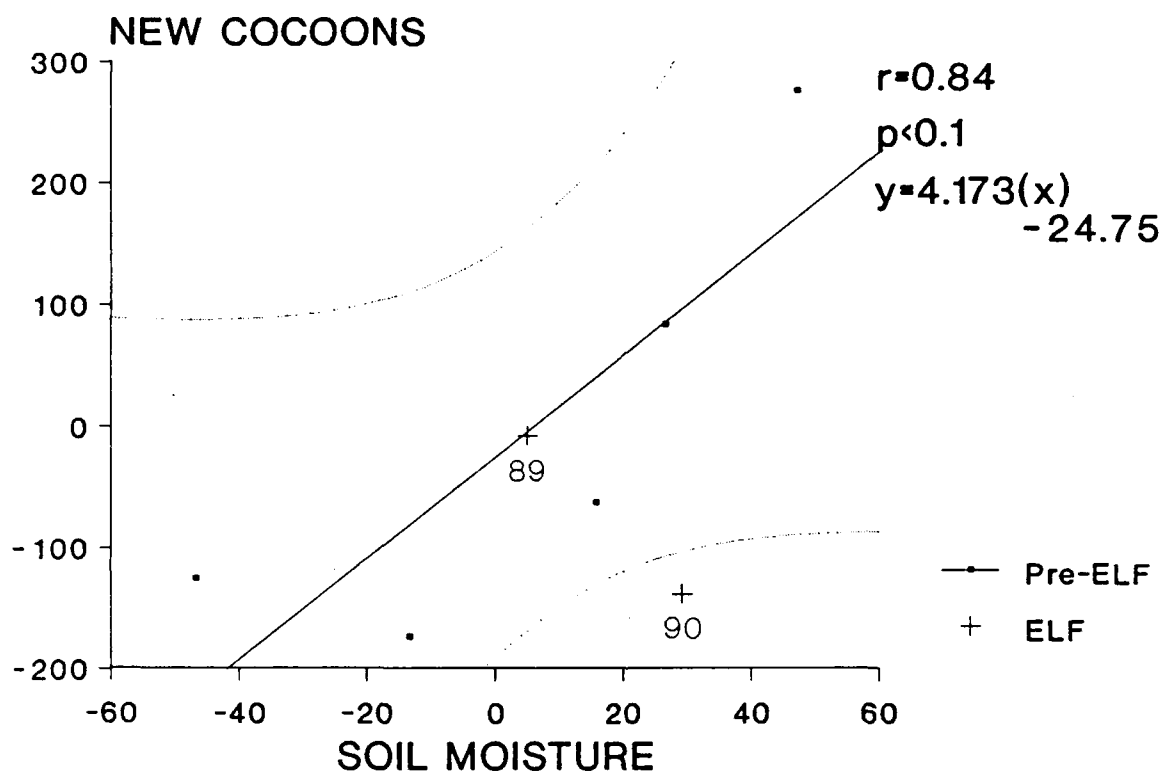


Fig. 23. Regression of new cocoon densities and A horizon moisture, *A. tuberculata*, using yearly summed deviations (Table 23); based on pre-ELF data,  $Y'_{89} = -3.5 \pm 162.1$ ;  $Y'_{90} = 97.1 \pm 199.2$ .

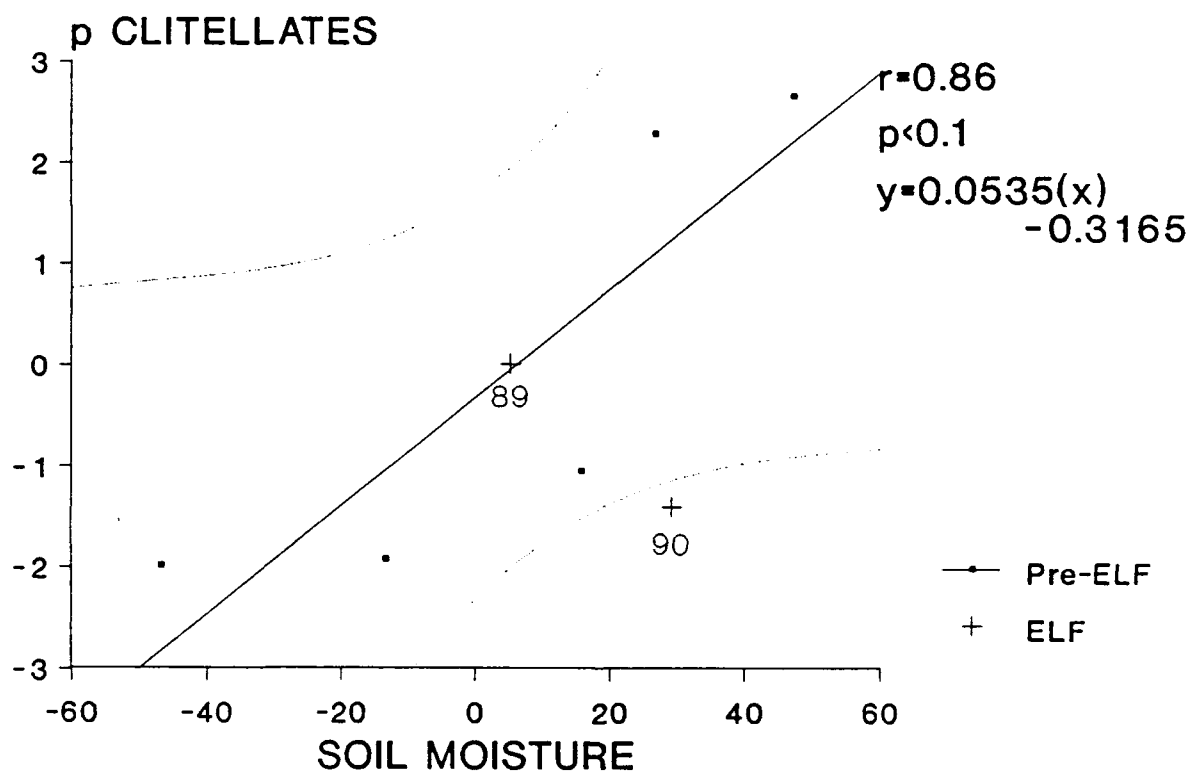


Fig. 24. Regression of proportion of adults clitellate on A horizon moisture, A tuberculata, using summed yearly deviations (Table 23); based on pre-ELF data,  $Y'_{89} = -0.044 \pm 1.933$ ;  $Y'_{90} = 1.246 \pm 2.371$ .

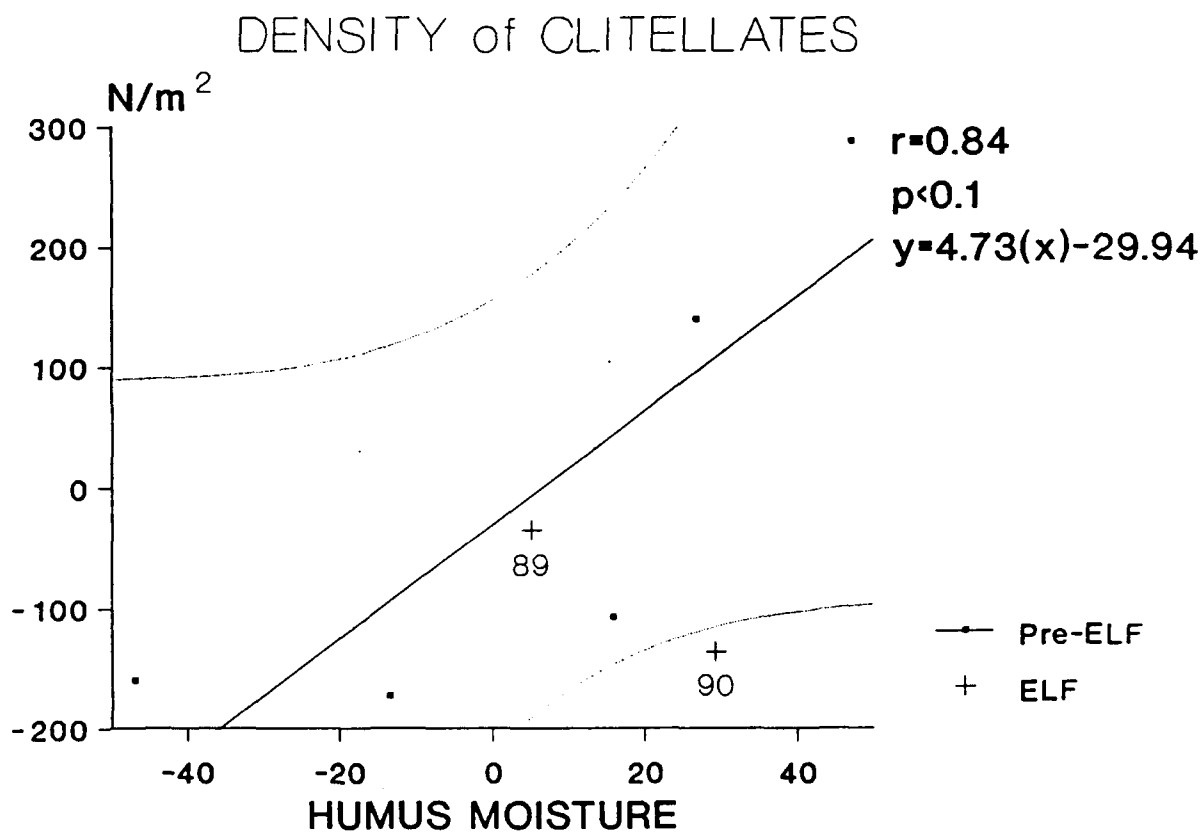


Fig. 25. Regression of clitellate density of A. tuberculata on A horizon moisture, using yearly summed deviations (Table 23).

points, and that confidence intervals are very wide, these results suggest that an ELF effect indeed occurred. Although we have yet to find a meaningful way to incorporate soil temperature into statistical analyses, preliminary and general comments are appropriate at this point:

a) high mid-summer temperatures do not adversely affect reproduction, given that moisture is adequate: the warmest summer so far occurred in 1987 (Tables 5 and 22), the year in which tuberculata cocoon production peaked (Table 24);

b) low temperatures are likely to influence rates of cocoon production, but occasionally high cocoon densities in spring and fall attest to the fact that temperatures at or above 10°C are not limiting for the species (e.g., Table 22);

c) the coolest summer so far occurred in 1990 (Table 5): given b) above, we submit that slightly cooler soil temperatures, rather than decreasing rates of cocoon production, should have enhanced them by alleviating what little moisture stress there was at the time.

In the following, we describe additional evidence to support our conclusions.

### 5.3. The case of turgida vs. tuberculata

We have repeatedly shown that reproductive and developmental patterns in these two Aporrectodea species are broadly similar, being comparable proportionally rather than in terms of absolute numbers.

For the five pre-ELF years, we can show that cocoon abundance (Fig. 26) as well as the proportion of adults clitellate (Fig. 27) are tightly

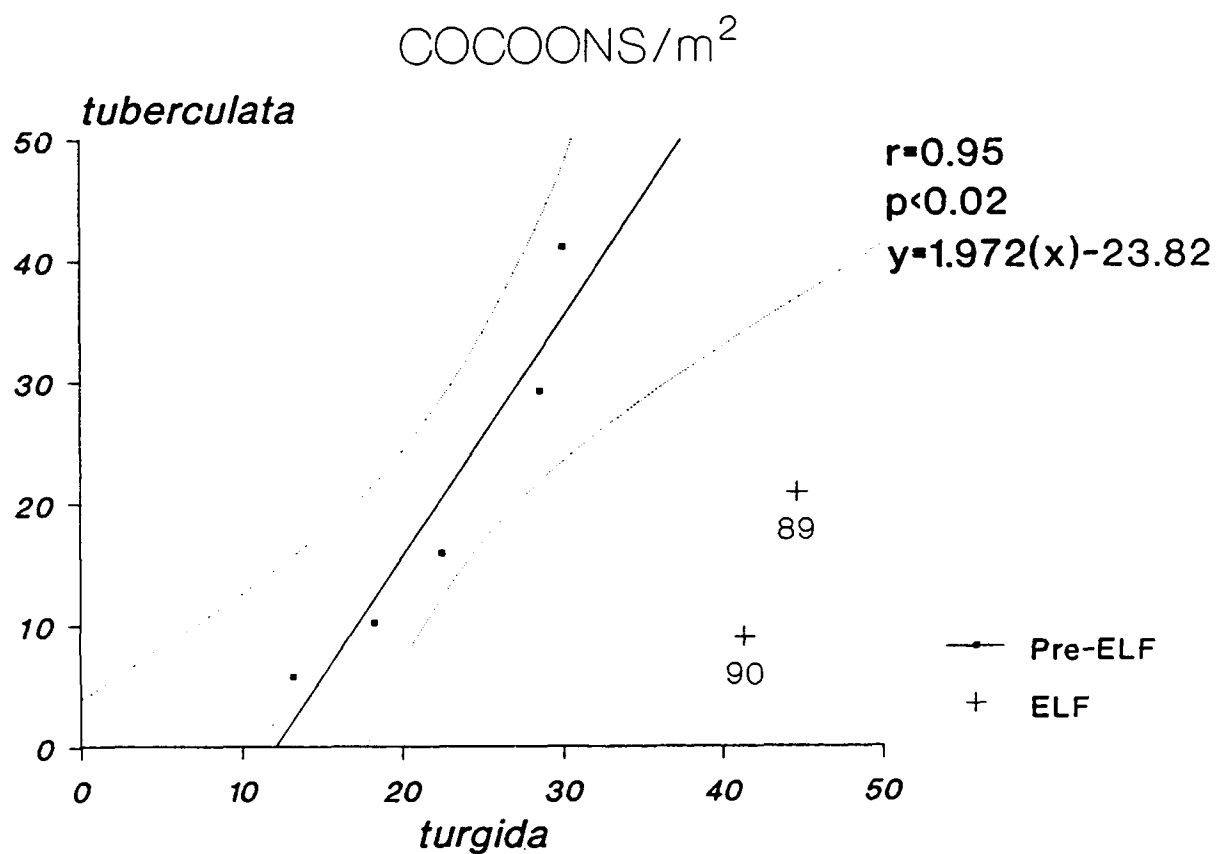


Fig. 26. Correlation between cocoon abundance (annual means, dates 2 through 12) of A. turgida and A. tuberculata in 1984 through 1988.



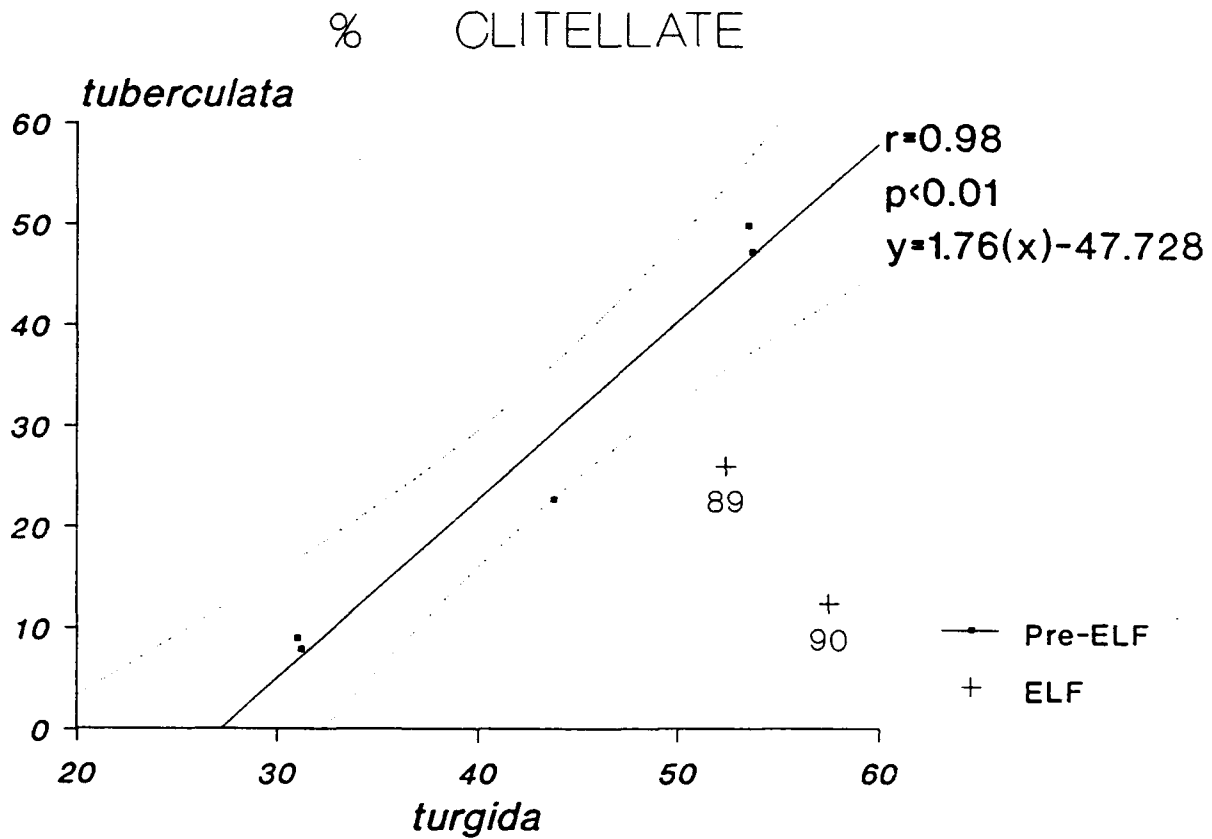


Fig. 27. Correlation between percent of adults clitellate (annual means, dates 2 through 12) in populations of A. turgida and A. tuberculata, 1984 through 1988.

correlated. For both parameters, observed 1989 and 1990 estimates are well below the lower 95% confidence limits (Figs. 26 and 27).

These results have to be evaluated with caution. It so happens that actual abundance of clitellate turgida, as well as cocoon densities, were higher than ever in 1989 and 1990 (Table 24). Loosely estimated in proportion to turgida cocoons, tuberculata cocoon densities of 50 to 60/m<sup>2</sup> in 1989 and 1990 may be unrealistically high, possibly exceeding the potential of the species. The proportion of adults in the clitellate state, however, is a relative value reflecting the species' response to moisture; 1989-90 means observed in turgida are in keeping with what we know either species to be capable of (Table 24). We believe these results support our earlier conclusion that tuberculata reproduction was depressed by EM fields in 1990, but questionably so in 1989.

Table 24. Mean annual densities of new cocoons and clitellates, and percent of adults clitellate, in A. turgida and A. tuberculata (dates 2 - 12).

|                            | 1984 | 1985 | 1986 | 1987 | 1988 | 1989 | 1990 |
|----------------------------|------|------|------|------|------|------|------|
| <u>Coc/m<sup>2</sup></u>   |      |      |      |      |      |      |      |
| turgida                    | 28.5 | 22.4 | 13.2 | 29.9 | 18.2 | 44.6 | 41.3 |
| tuberculata                | 29.2 | 15.9 | 5.8  | 41.1 | 10.2 | 20.9 | 9.0  |
| <u>Clit./m<sup>2</sup></u> |      |      |      |      |      |      |      |
| turgida                    | 31.4 | 19.8 | 13.6 | 27.4 | 18.9 | 34.2 | 36.8 |
| tuberculata                | 34.2 | 11.8 | 5.8  | 46.0 | 7.0  | 18.0 | 9.2  |
| <u>% clitellate</u>        |      |      |      |      |      |      |      |
| turgida                    | 53.7 | 43.8 | 31.0 | 53.5 | 31.2 | 52.4 | 57.5 |
| tuberculata                | 47.2 | 22.7 | 9.0  | 50.0 | 7.9  | 26.0 | 12.4 |

## 6. Lumbricus rubellus

For this species, which is common only in Test, we reiterate briefly the general developmental pattern illustrated in Figs. 28 and 29.

Clitellate individuals are present throughout the season, even in drought years, but favorable environmental conditions promote increased abundance of new cocoons (1987, 89, 90, Fig. 28). Old cocoons tend to accumulate in late fall and hatch in very early spring, leading to a pulse of class 0 recruits in May. Juveniles may reach class 4 weights late the same year or in the following spring. The data indicate that class 5 (large immatures and adults) is reached approximately 1.5 years after emergence. Consistently high numbers in that class (Fig. 29) indicate that adults may survive and reproduce for 2 or 3 years, thereby providing a stabilizing factor for overall population fluctuations.

This pattern, tentatively deduced from earlier years' data, was made abundantly clear in 1990 (Figs. 28-29). A uniquely large pulse of recruits entered the population in May of the year. Due to relatively frequent rains and consistently high litter moisture, mortality was reduced and we can follow that cohort through time, ending with high numbers of class 3 in October of 1990; a small proportion of juveniles entered class 4 at the same time (Fig. 29). After overwintering, class 3 individuals should predictably swell the numbers of class 4 and 5 individuals by summer of 1991, approximately 1.5 years after their emergence.

### 6.1. Annual population structure

By cumulating biweekly density estimates over each year, one can follow the fate of a given cohort and its effect on total population abundance (Table 25).

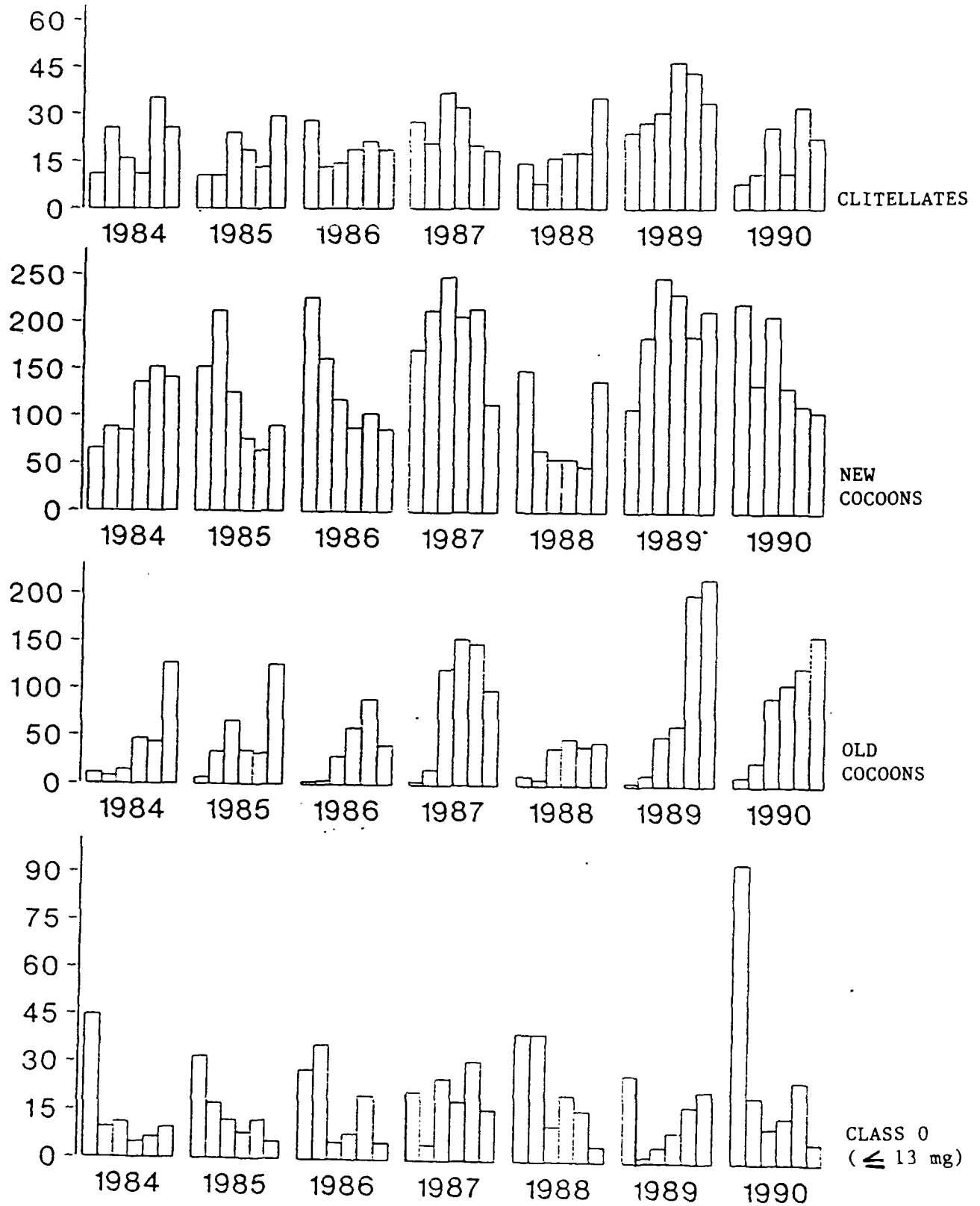


Fig. 28. Mean monthly abundance of clitellates, cocoons and hatchlings of *Lumbricus rubellus* in Test, 1984-1990 (May through October).

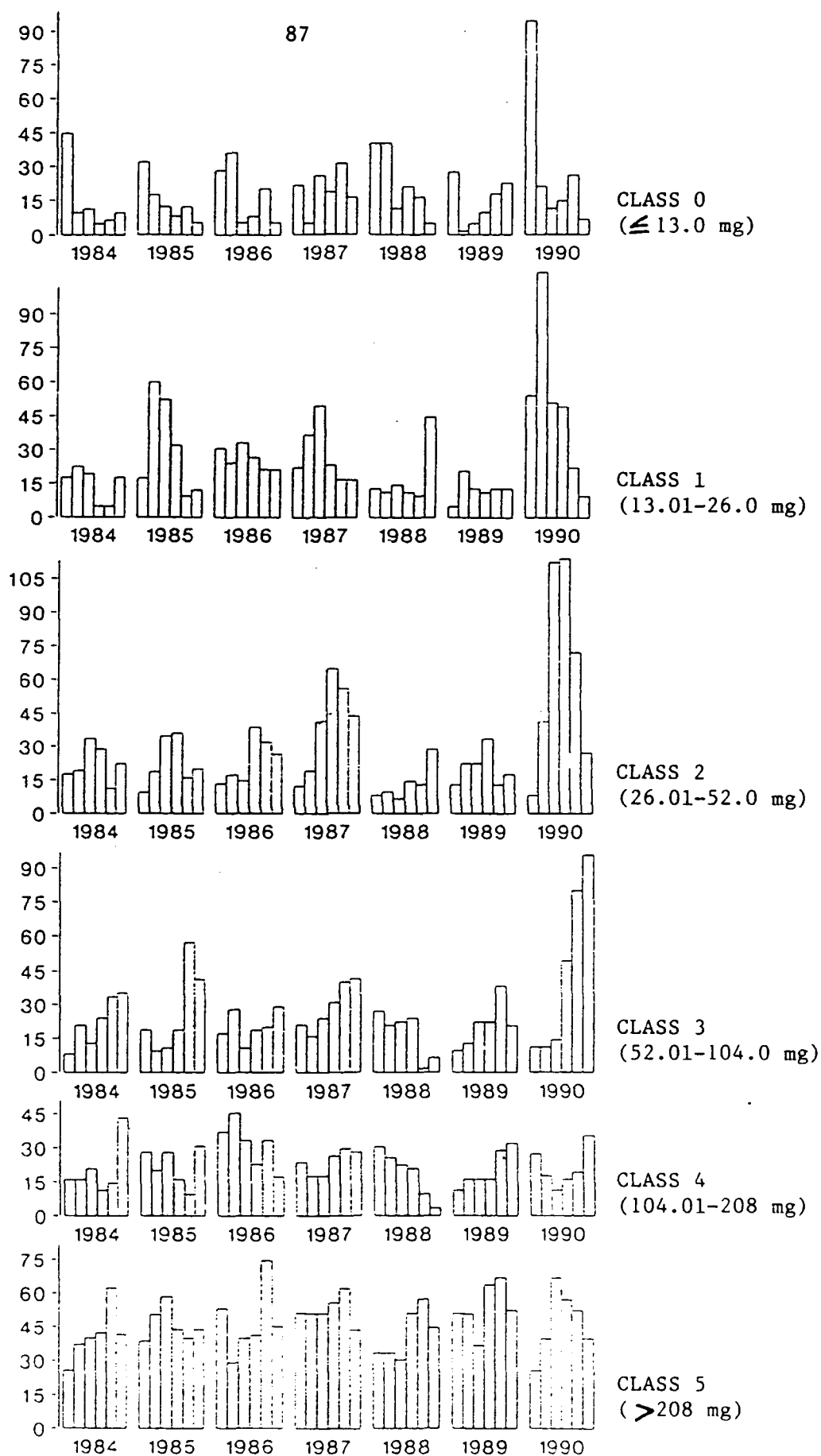


Fig. 29. Mean monthly abundance of *L. rubellus* in each weight class, 1984 to 1990 (May through October of each year).

Table 25. Cumulative abundances of L. rubellus over 12 sampling dates per year (weight classes as in Fig. 29).

|             | 1984 | 1985 | 1986 | 1987 | 1988 | 1989 | 1990 |
|-------------|------|------|------|------|------|------|------|
| New cocoons | 667  | 719  | 785  | 1173 | 515  | 1179 | 922  |
| CLASS 0     | 86   | 87   | 103  | 117  | 133  | 83   | 173  |
| CLASS 1     | 86   | 183  | 157  | 165  | 104  | 75   | 296  |
| CLASS 2     | 133  | 135  | 143  | 238  | 80   | 122  | 374  |
| CLASS 3     | 134  | 156  | 124  | 174  | 102  | 126  | 262  |
| CLASS 4     | 122  | 132  | 189  | 143  | 112  | 120  | 126  |
| CLASS 5     | 249  | 276  | 284  | 316  | 251  | 323  | 284  |
| Total worms | 810  | 968  | 1000 | 1154 | 782  | 849  | 1515 |

Abundance of new cocoons in one year determines, to a significant degree, hatchling densities in the following year. The relationship, illustrated in Fig. 30, can be used to predict the effect of high 1989 cocoon production : abundance of recruits in 1990 ( $173/\text{m}^2$ , Table 25) actually exceeded the confidence limits of the predicted density of  $137 \pm 27 / \text{m}^2$  (Fig. 30). Without doubt, ample rainfall in May and June of 1990 enhanced juvenile survival, leading to an unprecedented total population peak (Tables 17, 25).

## 6.2. Reproduction

We are attempting to use a variety of pre-ELF data compilations (e.g., deviations from 84-88 means, ref. section 5.1.) in order to arrive at predictive parameters for operational years. Given the relative imperviousness of the species, fluctuations in soil moisture, for instance,

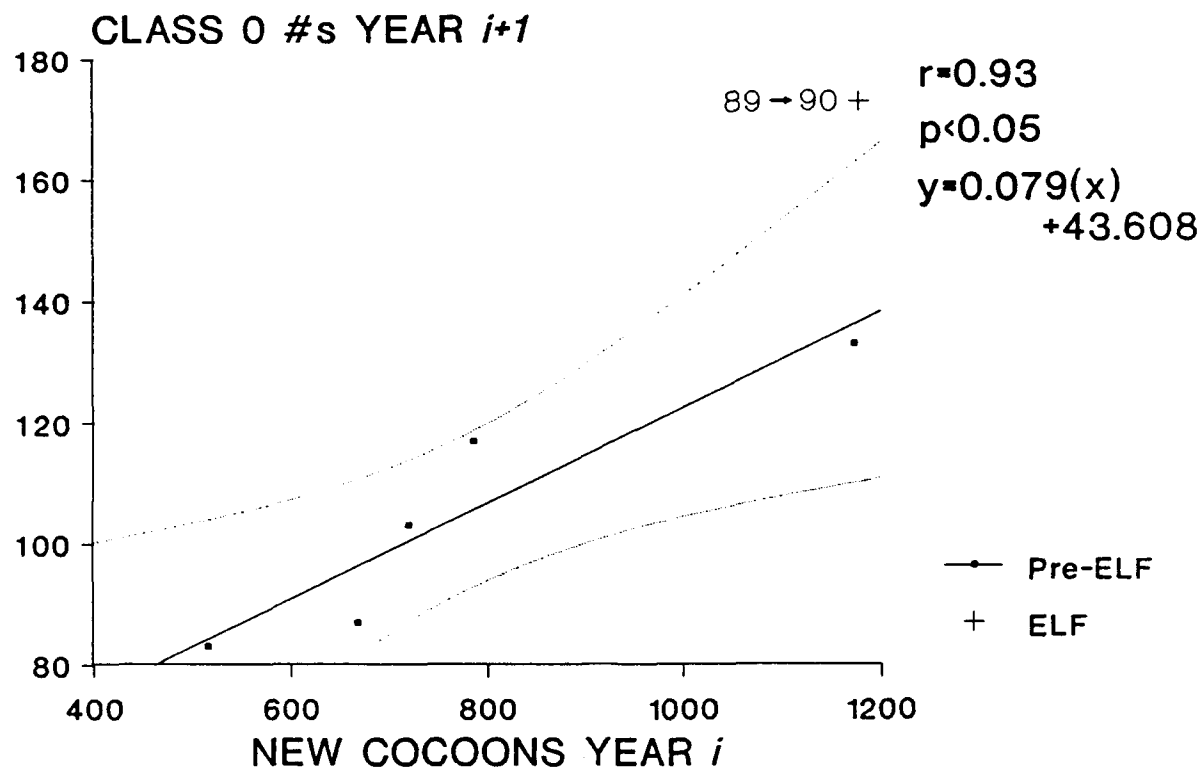


Fig. 30. Regression of new cocoon abundance of L. rubellus on hatchling densities in the following year.

have proven of little value. Pending further analyses, we here present only preliminary evaluations of reproductive parameters.

We first examine the ratio between new cocoon and clitellate abundance, leaving out the first and last date for reasons of potential observational error: at low spring and fall temperatures, cocoons may be classified as new while being chronologically older than our sampling period of two weeks. The lowest ratio occurred in the drought year of 1988, and 1989 and 1990 were not outlying (Table 26).

Table 26. Ratio of annual cocoon/clitellate densities of L. rubellus (means  $\pm$  SD), dates 2 to 12 per year.

|      | Ratio $\bar{x} \pm SD$ |
|------|------------------------|
| 1984 | 6.76 $\pm$ 4.35        |
| 1985 | 9.61 $\pm$ 8.08        |
| 1986 | 8.37 $\pm$ 4.78        |
| 1987 | 8.31 $\pm$ 3.39        |
| 1988 | 4.99 $\pm$ 2.43        |
| 1989 | 6.07 $\pm$ 1.53        |
| 1990 | 9.09 $\pm$ 5.59        |

The two parameters best related to each other are annual mean clitellate and cocoon densities. Based on five pre-ELF years, regression of cocoons on clitellates is indeed significant at  $P < 0.05$  (Fig. 31). Confidence limits for predicted 1989 cocoon abundance are understandably large, given that clitellate density was outside previously observed means; for 1990, observed mean cocoon abundance is actually slightly above the limits placed on predicted means (Fig. 31).



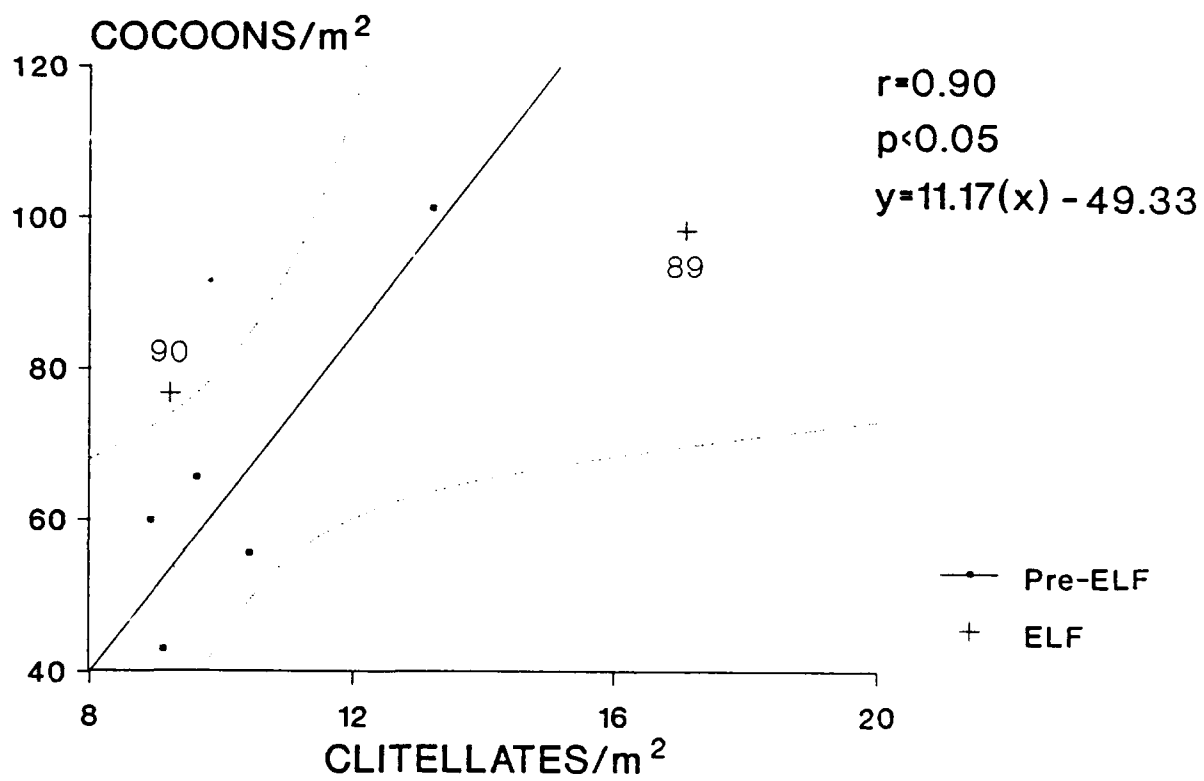


Fig. 31. Regression of mean annual cocoon density on clitellate density of L. rubellus.

The average percent (of all adults) clitellate ranged from 82% in 1984 and 1989 to 59% in 1990. Given that adults are mainly A horizon dwellers, we regressed mean annual percent clitellate on soil moisture (using deviations from 20%). With  $r = 0.69$ , and  $P < 0.2$ , the relationship was not tight. Even so, based on 1984-88 regression data, the observed mean for 1989 (82.6% clitellate) was just above the upper limit of the predicted mean ( $72.6 \pm 7.1 \%$ ). In 1990, the observed 59.4% was significantly lower than the predicted  $75.6 \pm 8.7 \%$ , at  $P < 0.05$ .

Regression of mean cocoon densities on soil moisture deviations gave similar results ( $r = 0.75$ ,  $P < 0.2$ ). The observed 1989 mean of 98.3 cocoons /m<sup>2</sup> was significantly above the predicted mean of  $65.5 \pm 23.8$ ; in 1990, observed ( $76.8 /m^2$ ) and predicted values ( $75.6 \pm 29.3$ ) were practically equal.

Based on these initial analyses, we have no conclusive evidence regarding deviant L. rubellus behavior in operational years. Continued monitoring of the population is indicated, however, to clarify potential questions. In particular, the low proportion of adults in the clitellate state seems bothersome: 1990 was certainly a "moist year", comparable to 1984, and somewhat more favorable than 1989.

#### 7. Dendrobaena octaedra

In our 1989 report, we documented and discussed the differences between Test and Control populations of D. octaedra in detail. In summary, we arrived at the conclusion that population structure differed greatly between sites, abundance of developmental (weight) classes lending itself poorly to rigorous site comparison; basic characteristics of reproduction

inherent to the species do allow site or year comparisons through correlation and regression analysis.

### 7.1. Parameters of reproduction and development

#### 7.1.1. Old cocoons and hatchlings

The time of hatchling (class 0) emergence is a result of developmental rates of cocoons, and their seasonal abundance is also dependent on cocoon production during the preceding months. We therefore compared biweekly hatchling densities in Test and Control by correlation. Despite general similarities in emergence patterns (peak abundance in the first half of the season), the parameter does not appear useful (Table 27). Coefficients are relatively low, and often not significant at all, specifically in years when total numbers recovered from the Test site are very low (1984, 1989). It is evident, however, that hatchling abundances were well correlated over time in 1990 (Table 27).

Table 27. Correlation coefficients for biweekly densities of class 0 immatures of D. octaedra in Test and Control.

|      | N  | r     | P     |
|------|----|-------|-------|
| 1984 | 10 | -0.16 | NS    |
| 1985 | 11 | 0.59  | NS    |
| 1986 | 11 | 0.78  | 0.01  |
| 1987 | 8  | 0.70  | 0.05  |
| 1988 | 10 | 0.68  | 0.02  |
| 1989 | 11 | 0.32  | NS    |
| 1990 | 11 | 0.87  | 0.001 |

Abundances of old (fully developed) cocoons, typically tapering off rapidly after their May and June peak, mainly reflect developmental rates during the preceding fall and winter. Correlation coefficients for this parameter were significant at  $P < 0.02$  or better (Table 28). The only exception was 1989: in the Test site, no old cocoons were found in the spring at all. The very low cocoon production in the drought year of 1988 apparently led to "missing" the few old cocoons present in early 1989. Given reasonable numbers, we should be able to continue using this parameter for between-site comparison.

Table 28. Correlation coefficients for biweekly abundances of old cocoons of D. octaedra in Test and Control.

|      | N  | r     | P     |
|------|----|-------|-------|
| 1984 | 10 | 0.997 | 0.001 |
| 1985 | 11 | 0.91  | 0.02  |
| 1986 | 11 | 0.99  | 0.001 |
| 1987 | 8  | 0.91  | 0.02  |
| 1988 | 10 | 0.998 | 0.001 |
| 1989 | 11 | -0.03 | NS    |
| 1990 | 11 | 0.90  | 0.02  |

#### 7.1.2. Adults and new cocoons

Much as in other species, the proportion of adults clitellate and the number of cocoons they produce is of major interest in D. octaedra.

As a simple first approach, we examine the average ratio of cocoon : clitellate densities for each year (Table 29). Only data from

mid-June to late September are used, in order to eliminate observational error (classifying cocoons as new during low-temperature seasons). In both sites, this ratio is somewhat variable, but neither 1989 nor 1990 were outlying (Table 29).

Table 29. Annual (mean  $\pm$  SD, N = 8) ratio of new cocoon : clitellate densities of D octaedra in Test and Control.

|      | TEST            | CONTROL         |
|------|-----------------|-----------------|
| 1984 | 7.7 $\pm$ 3.93  | 9.8 $\pm$ 4.48  |
| 1985 | 11.7 $\pm$ 6.49 | 9.2 $\pm$ 5.08  |
| 1986 | 5.7 $\pm$ 2.47  | 5.4 $\pm$ 2.05  |
| 1987 | 5.4 $\pm$ 1.74  | 5.2 $\pm$ 0.89  |
| 1988 | 5.8 $\pm$ 3.14  | 13.1 $\pm$ 5.33 |
| 1989 | 6.8 $\pm$ 4.52  | 8.7 $\pm$ 4.55  |
| 1990 | 7.1 $\pm$ 4.31  | 7.9 $\pm$ 2.44  |

Given that the percentage of adults clitellate as well as the number of cocoons produced are influenced by year-specific environmental variables, we can examine annual averages and their Test/Control relationships.

"Percent clitellates" during the five pre-ELF years were significantly correlated between sites (Fig. 32); cocoon densities yielded a slightly lower  $r$  and wider confidence intervals (Fig. 33). In both cases, 1989 and 1990 data fell well within 95% confidence limits.

Finally, we may analyze the mean annual ratios of clitellate : cocoon abundances within the Test population alone. For the pre-ELF years, the relationship was significant at  $P < 0.02$ , and observed ratios in 1989 and 1990 were well within the 95% CL of those predicted by regression (Fig. 34).

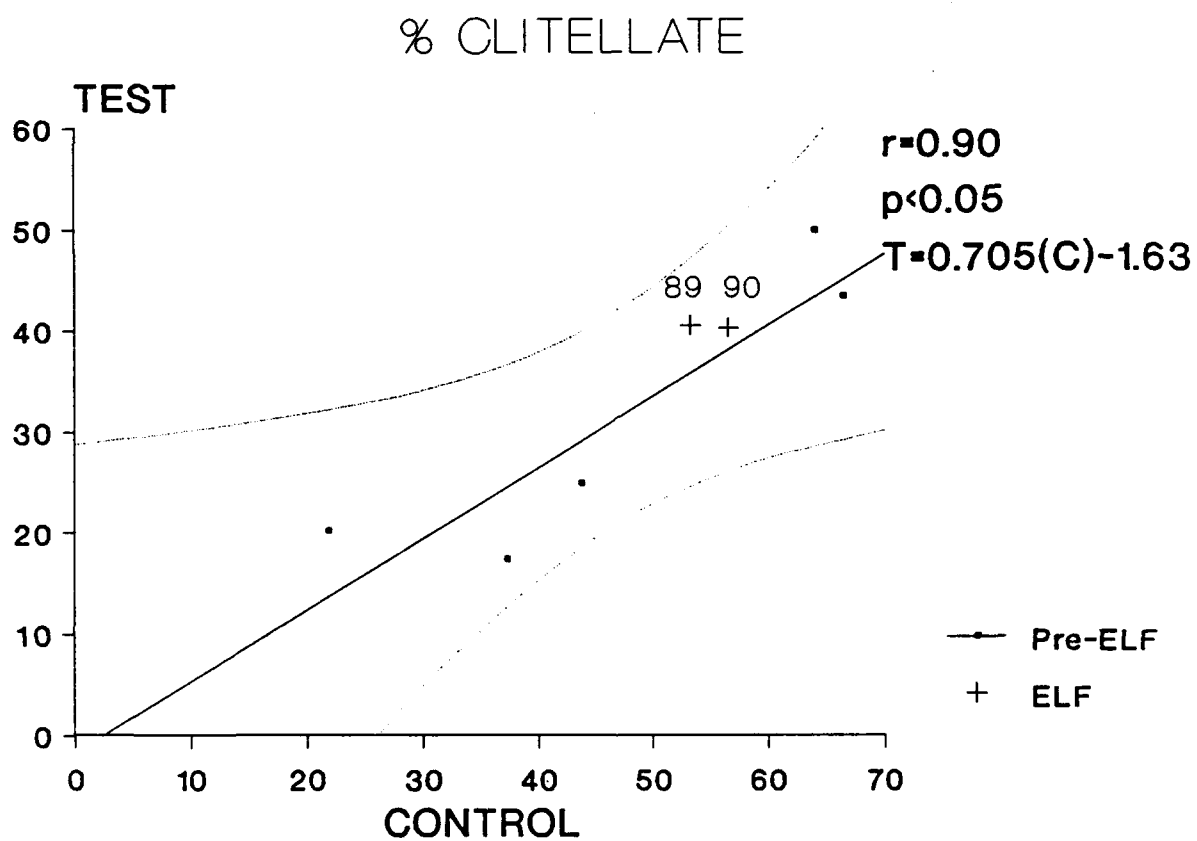


Fig. 32. Correlation between the mean annual percent of adult D. octaedra in the clitellate state in Test and Control.

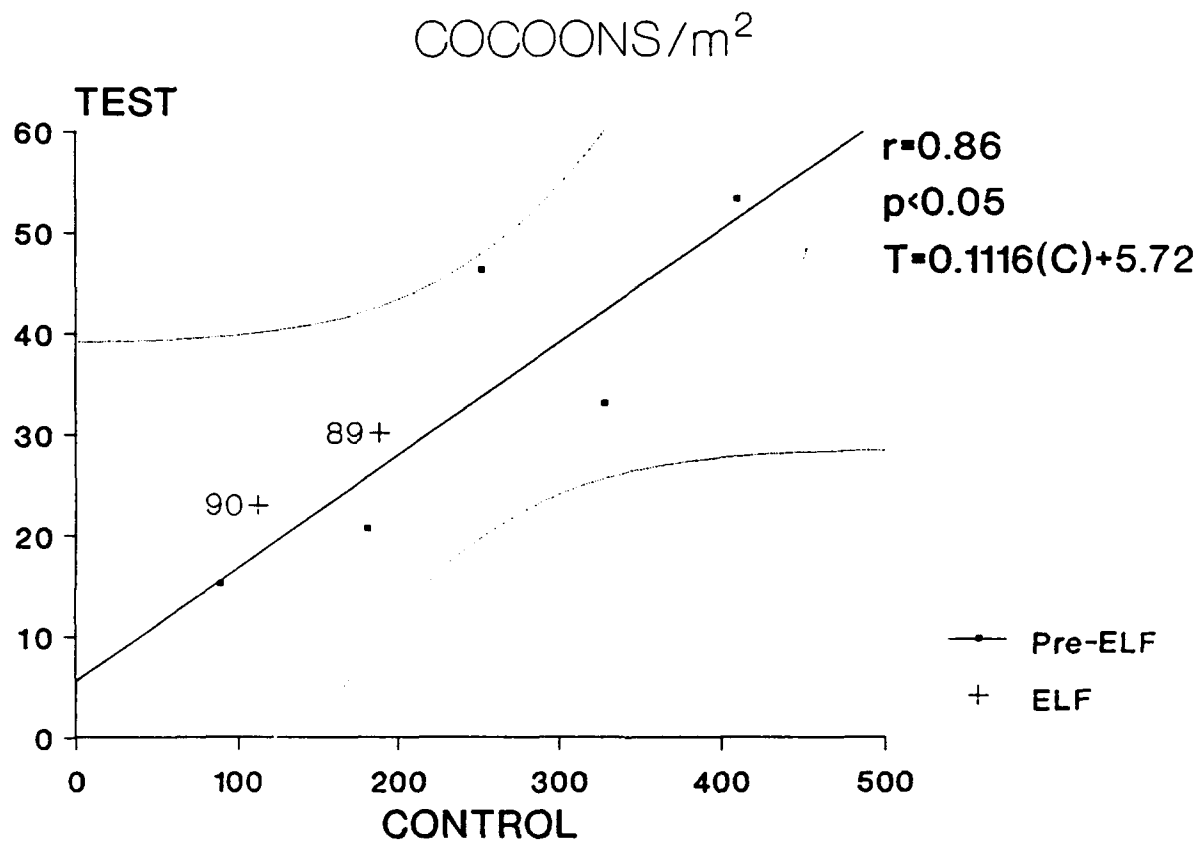


Fig. 33. Correlation between the mean annual cocoon abundances of D. octaedra in Test and Control.

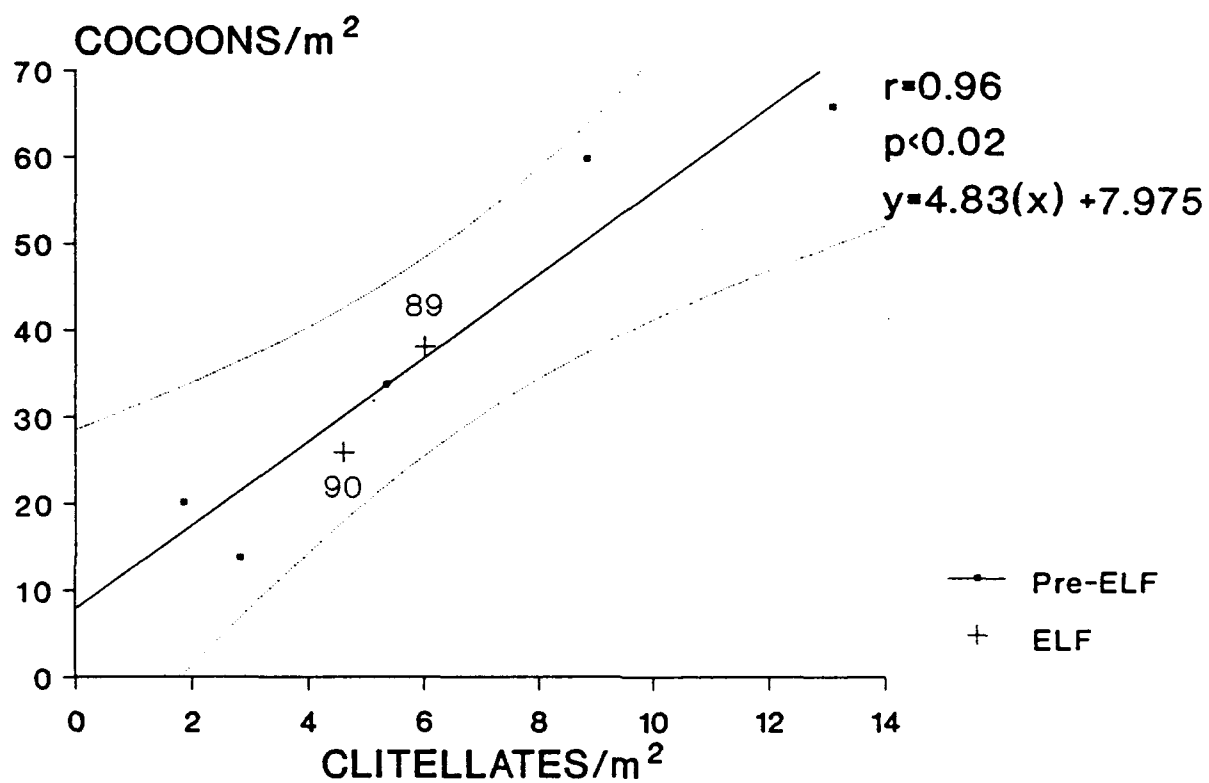


Fig. 34. Regression of cocoon on clitellate abundance (annual means) of D. octaedra in the Test site.



The same relationship between cocoon and clitellate abundance of D. octaedra in the Control site was more variable than in Test ( $r = 0.84$ ,  $P < 0.1$ ,  $N = 5$ ); but the regression slopes ( $b_{\text{Test}} = 4.83$ ,  $b_{\text{Control}} = 5.02$ ) did not differ significantly between sites.

It is important to consider, however, that we do not expect the relationship between cocoons and clitellates (Fig. 34) to differ greatly between years, because it is a basic attribute of the species (ref. also A. tuberculata, Fig. 22). An answer to the question posed earlier (should there have been more clitellates?) has to be deferred until results of further analyses are available. Obviously, we need to extricate significant, predictive relations between environmental variables and reproductive success of D. octaedra.

In summary, based only on preliminary analyses we cannot demonstrate any ELF effects in D. octaedra. We make note, however, of the relatively low population abundance in Test (Table 17), particularly in 1990 when above-average moisture conditions should have promoted increased numbers.

## 8. Conclusions

We have no good evidence to date that D. octaedra or L. rubellus were adversely affected by ELF operation, but low population density of the former, and a significantly lowered proportion of reproductive adults in the latter species in 1990 make continued monitoring advisable.

Evidence of reduced reproduction in A. tuberculata is at least strong enough to warrant controlled experimentation, while continuing the existing field sampling program. We can only outline the nature and goals of planned experiments; exact protocols will not be developed

until April or May of this year, with the help of technical support from IITRI.

We anticipate using retrieveable enclosures made of netting, stocked with a number of earthworms and placed in Test and Control soils. Parameters of interest would be earthworm weight, sexual development and cocoon production over time.

Are epigeic species not detectably affected because they "escape" into leaf litter and thereby avoid EM fields in the soil? Is a lowered proportion of clitellates in L. rubellus a sign of "intermediate exposure" as the species moves between litter (where it feeds) and soil strata (where it deposits cocoons)? Measurement of EM fields in the soil at various depths, at the soil surface and in the litter stratum could provide valuable information on potential causes for differential EM effects on species frequenting different substrate layers.

Will individuals continuously exposed to EM fields since the cocoon stage be affected differently than those exposed when they were already mature? We strongly suggest that two fully operational years, more than likely discrepant in terms of environmental conditions, will be insufficient for conclusive findings. Long-term consequences may not be predictable at all, since potential effects on population abundance may not begin to emerge for at least two years hence.

Quantification of relationships between soil moisture, EM field intensities, and earthworm response should be one of the major experimental goals. Since we do not know how earthworms "experience" EM fields at different moisture levels, we could thereby determine empirically what the relative effects of both variables are likely to be. These data would aid interpretation of field-derived estimates of population attributes.

Finally, one would wish to interpret data at the community and system levels: if the dominant endogeic species is adversely affected, will other, less affected species increase in importance and take its place? Will litter disappearance rates be noticeably affected by changes in community structure? These and other questions which may arise can not be answered clearly at the end of two operational years.



## VI. LITTER INPUTS AND DECOMPOSITION

### 1. Litter inputs

Temporal patterns of litterfall (Fig. 35) were tightly correlated between sites in 1990, for the dominant Acer saccharum as well as for basswood and total litter input ( $r = 0.99$  in all cases). Total dry mass of litterfall did not differ between sites and was consistent with previous years (Table 30).

Table 30. Annual litter inputs (g dry /m<sup>2</sup>), 1983-1990, by the dominant Acer saccharum and by all species together in Test and Control.

|       |    | 1983 | 1984 | 1985 | 1986 | 1987 | 1988 | 1989 | 1990 |
|-------|----|------|------|------|------|------|------|------|------|
| Maple | T: | 189  | 177  | 203  | 176  | 161  | 191  | 180  | 169  |
|       | C: | 221  | 179  | 199  | 189  | 180  | 198  | 162  | 172  |
| Total | T: | 278  | 259  | 286  | 252  | 231  | 276  | 269  | 246  |
|       | C: | 305  | 264  | 289  | 284  | 275  | 301  | 258  | 261  |

### 2. Litter standing crops and turnover

NOTE: for 1990 leaf litter samples (N = 40 /2 weeks) we can only report oven-dry mass data at this time. All have been ground, but ashing is not yet completed.

In keeping with earlier observations, oven-dry litter mass estimates for 1990 (Fig. 36) differed somewhat between sites, being slightly higher in Control. Following the procedure justified in 1989, we use means of "arthropod" and "moisture" samples (they are taken in pairs)

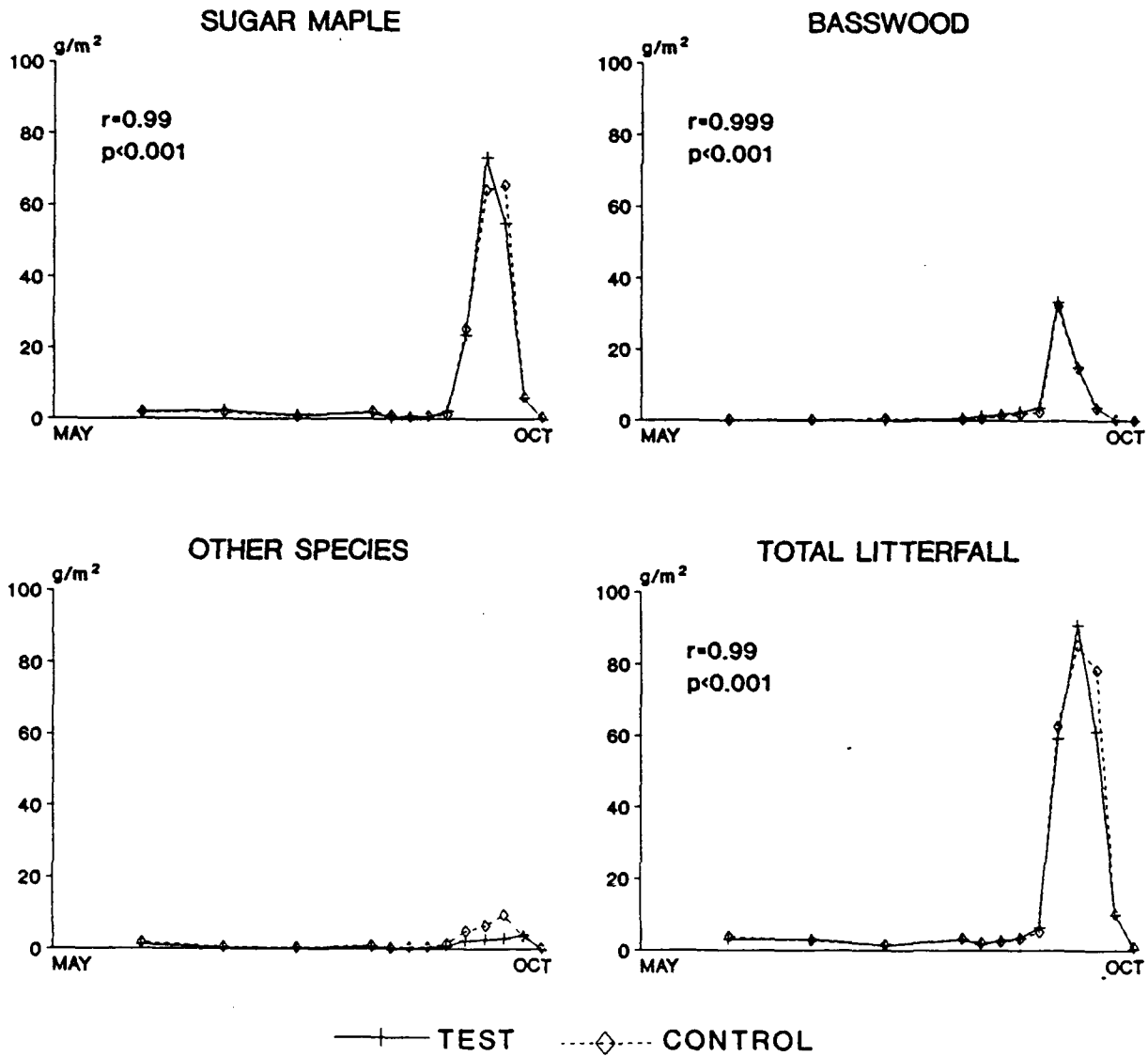


Fig. 35. Litter inputs (g oven-dry / m<sup>2</sup>) in Test and Control, 1990.

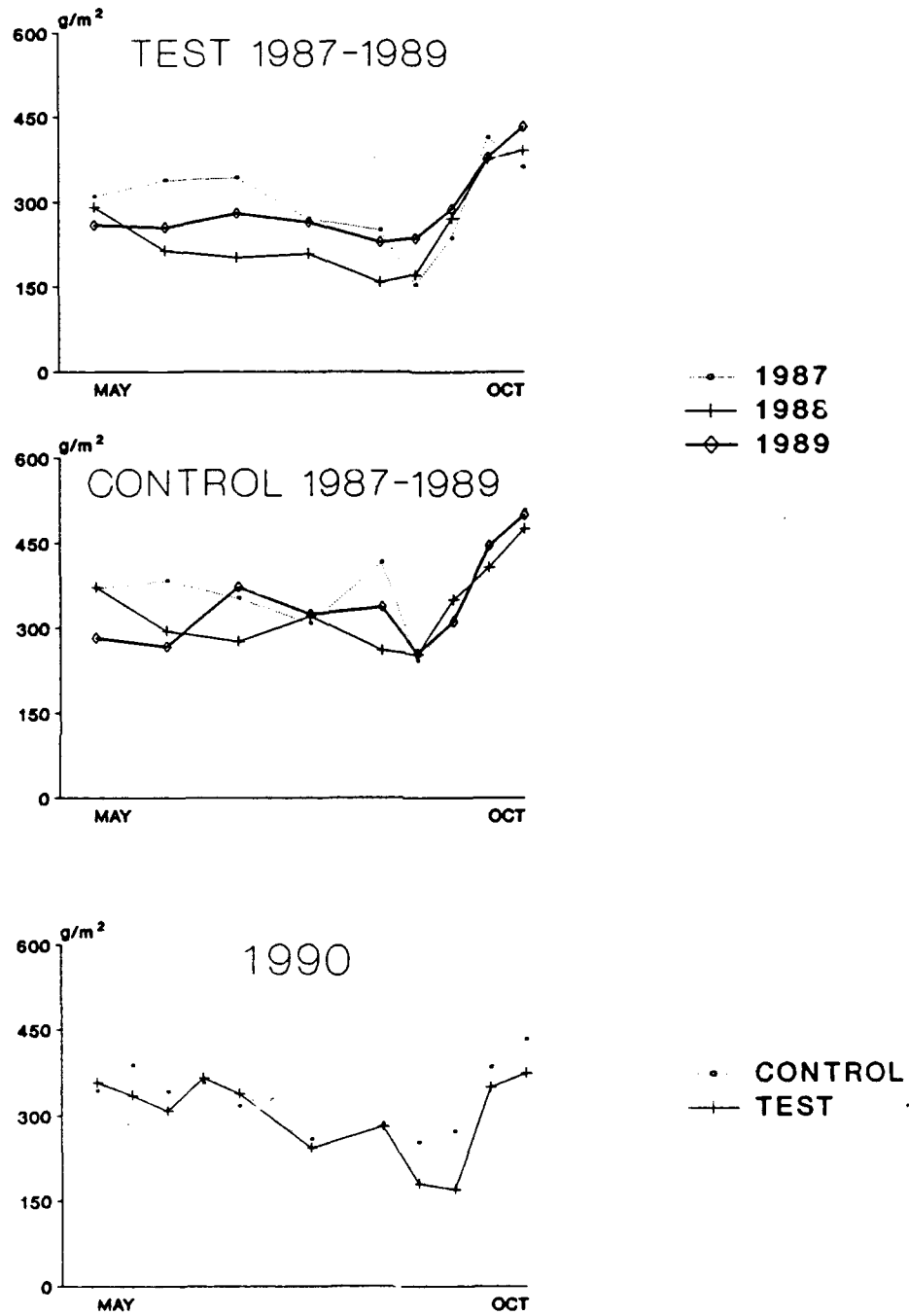


Fig. 36. Seasonal litter standing crops (oven-dry  $\text{g/m}^2$ ) in Test and Control sites, 1987 to 1990.

as individual data points, for an N of 20 /site /date. Anova of seasonal standing crops shows significant site and date effects, as expected; but not site x date interactions, i.e., seasonal increases and decreases in standing crops are again consistent between sites (Table 31).

Table 31. Anova table for seasonal litter standing crops in Test and Control, 1990.

| Source      | df  | SS        | MS       | F      | P     |
|-------------|-----|-----------|----------|--------|-------|
| Replication | 19  | 1336.380  | 70.336   | 1.415  | 0.114 |
| Site        | 1   | 401.088   | 401.088  | 8.070  | 0.005 |
| Date        | 12  | 14637.646 | 1219.804 | 24.544 | 0.000 |
| Site x date | 12  | 616.360   | 51.363   | 1.033  | 0.416 |
| Error       | 475 | 23607.096 | 49.699   |        |       |
| Total       | 519 | 40598.570 |          |        |       |

Turnover time estimates based on oven-dry mass were consistent with previous years and did not differ from 1985-1989 means (Table 32). Once again we observe that turnover time is slightly higher in Control, although not as discrepant as it had been in 1989. It is possible that, as numbers of Dendrobaena octaedra (ref. section V.2.) begin to recover, turnover rates in Control are returning to an average of approximately 1 year.



Table 32. Turnover times for leaf litter standing crops in Test and Control.

|         | 1985 | 1986 | 1987 | 1988 | 1989 | 1990 |
|---------|------|------|------|------|------|------|
| TEST    | 0.99 | 0.97 | 1.22 | 0.82 | 1.03 | 0.93 |
| CONTROL | 0.97 | 1.00 | 1.28 | 1.00 | 1.37 | 1.08 |

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1985-1989 means  $\pm$  95% CL: TEST =  $1.0 \pm 0.19$  years

CONTROL =  $1.10 \pm 0.26$  years

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Note: turnover time =  $1/k$ ;  $k = -\ln(1-k')$ ;  $k'$  = input / maximum stdg. crop.

### 3. Litterbags

#### 3.1. Experimental protocol

Several years ago, our plans had included first-year as well as second-year litter decay observations. We have since revised this protocol for two reasons: a) second-year data, with the exception of May of the second year after field placement, become more and more variable, as well as unreliable: retrieval of litterbags, for instance, often involves extricating the contents from grasses and herbs which have grown up through them, resulting in potential loss of material. And b) available areas for litterbag placement within site boundaries are becoming limiting. Space limitations were particularly noticeable in 1990, when the first "Exchange series" of litterbags (explained below) was implemented.

We currently restrict litterbag experiments to obtaining first-year (plus May and June of the second year, if possible) data. Procedural

error is thereby minimized, data are statistically tight as well as biologically meaningful, and multiple-year comparisons will be possible.

Forest floor space can thus be allocated to two separate series of litterbags which will help interpretation of site differences. One of these represents the continuation of past experiments (Test litter in Test, Control litter in Control). The second, which we implemented in November of 1990, consists of Test leaves placed in Control and vice versa (Exchange series). A simple flow chart (Fig. 37) shows past as well as planned litterbag series through 1992. Although the project is scheduled to end in October of 1992, we anticipate retrieving the last of the 1991 litterbags in early November of 1992 in order to complete a third ELF year data set.

We have continued to use the same procedures and materials (flexible 20 mm mesh netting) as in previous years. All 1990 samples have been processed, and ash-free dry weights form the data base for analysis.

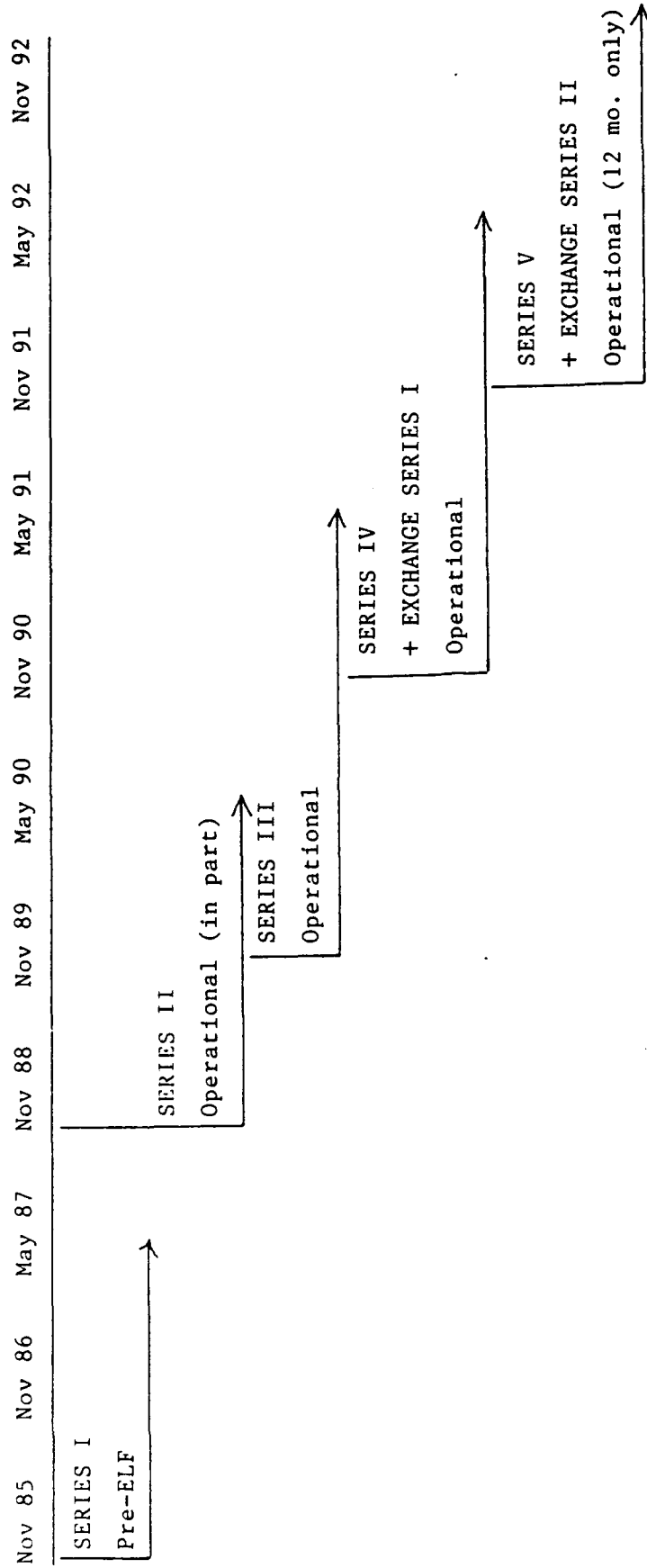


Fig. 37. Past and future schedule of litterbag studies in Test and Control.

### 3.2. Results

Results (in % of initial AFDW remaining) available to date are summarized in Fig. 38. For Series I (initiated November 1985) and Series II (Nov 1988), data for May of the second year of decay are included; for Series III (Nov 1989), May of the current year 1991 will yield the last data point.

Recalling our discussion of results in the 1989 report, discrepancies between sites were first encountered in the fall of 1989, after the 1988 litterbag series had been in the field for approximately 1 year. Decay rates in Control were significantly lower than in Test by October and November of 1989 ( $P < 0.01$  and  $< 0.001$  respectively, two-sample  $t$  tests). We tentatively ascribed the difference to an all-time low population of Control D. octaedra, a major litter consumer. If our interpretation is indeed correct, it now appears that this effect lasted into the following year of 1990 (Fig. 38). Numbers of D. octaedra, severely depressed from late summer of 1989 through spring of 1990, did not increase until the early summer influx of hatchlings occurred. Without controlled experimental data, we can only surmise that "conditioning" (or lack of it) of leaf litter during the first months of decay, particularly in fall and spring, influenced the rate of its decay later on. Indeed, if these population fluctuations are a regular occurrence in the Control site, then they may explain, over the long term, the higher litter standing crops (accumulations of residues) in that site.

A number of analyses of variance were used to test litterbag series (= years) and site effects (Table 33).

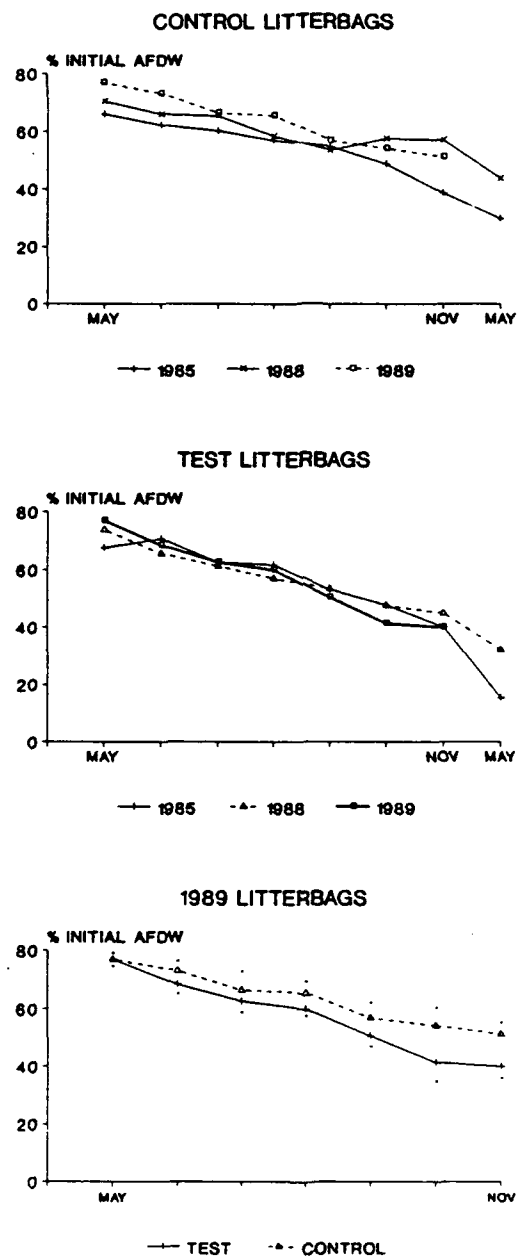


Fig. 38. Disappearance of leaf litter from litterbags (in % of initial AFDW remaining), litterbag series I, II and III; 95% CL shown only for Series III.

Table 33. Anova table for seasonal litter disappearance estimates in Test and Control sites; N /date = 10 or more; for identification of Series, see Fig. 37.

| Source  | df  | SS        | MS       | F        | P     |
|---|-----|-----------|----------|----------|-------|
| <u>A. TEST: SERIES I AND II THROUGH MAY OF SECOND YEAR</u>        |     |           |          |          |       |
| Series  | 1   | 0.6681    | 0.668    | 0.0196   | 0.889 |
| Date  | 7   | 25895.873 | 3699.410 | 108.5611 | 0.000 |
| Series x date   | 7   | 575.979   | 82.283   | 2.4146   | 0.023 |
| Error   | 146 | 4975.205  | 34.077   |          |       |
| <u>B. CONTROL: SERIES I AND II THROUGH MAY OF SECOND YEAR</u>     |     |           |          |          |       |
| Series  | 1   | 1910.283  | 1910.283 | 38.3499  | 0.000 |
| Date  | 7   | 14676.275 | 2096.611 | 42.0905  | 0.000 |
| Series x date   | 7   | 1515.617  | 216.517  | 4.3467   | 0.000 |
| Error   | 146 | 7272.553  | 49.812   |          |       |
| <u>C. TEST: SERIES I, II AND III, FIRST YEAR ONLY</u>             |     |           |          |          |       |
| Series  | 2   | 0.1169    | 0.058    | 0.0020   | 0.998 |
| Date  | 6   | 25172.442 | 4195.407 | 141.9117 | 0.000 |
| Series x date   | 12  | 1265.046  | 105.421  | 3.5659   | 0.000 |
| Error   | 221 | 6533.533  | 29.563   |          |       |
| <u>D. TEST vs. CONTROL: SERIES I, II AND III, FIRST YEAR ONLY</u> |     |           |          |          |       |
| Series  | 2   | 1291.064  | 645.532  | 18.2067  | 0.000 |
| Site  | 1   | 580.187   | 580.187  | 16.3637  | 0.000 |
| Date  | 6   | 35526.010 | 5921.002 | 166.9970 | 0.000 |
| Series x site   | 2   | 1310.378  | 655.189  | 18.4791  | 0.000 |
| Series x date   | 12  | 2300.840  | 191.737  | 5.4078   | 0.000 |
| Site x date   | 6   | 1142.220  | 190.370  | 5.3692   | 0.000 |
| Seriesxsite x date  | 12  | 690.616   | 57.551   | 1.6232   | 0.083 |
| Error   | 422 | 14962.318 | 35.456   |          |       |

A. Test only, series I and II (Table 33): if we tentatively treat the 1988 series, sampled in 1989, as pre-ELF, then we find no difference in litter disappearance rates between years.

B. Control only, series I and II: all effects were highly significant, confirming the discrepancies between series (=years) discussed above and illustrated in Fig. 38.

C. Comparing first-year decay rates within Test, i.e., three series of which one was sampled during an operational year, we again detect no differences between series.

D. First-year decay in Test vs. Control, for the three series as above (Table 33 D): all main effects and two-way interactions are highly significant; of the latter, series x site interactions point out the anomaly observed in Control for the 1988 and 1989 litterbag series.

Significant series x date interactions (within Test in particular, Table 33 C) would indicate differences over the course of litter disappearance; we submit that they are merely a reflection of the very small sample variances typical of these data, and are not biologically significant. One should expect differences in month-to-month decay to be caused by year- and date-specific environmental conditions, through their effects on decomposer activity.

In summary, there is no evidence that litter decay rates in the Test site were discrepant in the first fully operational year of 1990. Between-year differences in Control probably reflect extreme population fluctuations of D. octaedra, an interpretation which we hope to validate in 1991-92. The Exchange litterbag series will also aid future interpretation in terms of the site- and year- specificity of litter decay.





APPENDIX A:

Electromagnetic field measurements  
in detail





IIT Research Institute  
10 West 35th Street  
Chicago, Illinois 60616-3799

312/567-4000

8 January 1991

Dr. Renate Snider  
Department of Zoology  
Michigan State University  
East Lansing, MI 48824-1115

Dear Dr. Snider:

The purpose of this letter is to provide you with documentation of the 1990 ELF electromagnetic (EM) field measurements made by IITRI at your study sites. Specific measurement dates were 2 and 8 October 1990. EM measurement data from previous years are also included.

#### **Study Sites**

This year, EM measurements were made at 8 locations at the study sites listed in Table 1. Measurement positions within each study site are diagrammed in Figures 1-2. All measurement points characterized in 1986 through 1989 were remeasured in 1990. Please check these figures for accuracy and comment on the suitability of the EM field measurement locations to your study requirements.

#### **MTF Operations - 1990**

The NRTF-Republic typically operated continuously and at full power during 1990. Regular exceptions to this were scheduled weekly maintenance periods lasting for about 5 hours on Tuesdays and Thursdays. Detailed summaries of the antenna operating conditions are being prepared and will be presented in the annual report documenting EM field measurements and engineering support for the Ecological Monitoring Program in 1990.

#### **EM Measurement Protocol**

Measurements of 76 Hz EM fields were conducted in 1990 at both study sites during operation of both antennas with 150 ampere currents. Ambient 60 Hz EM fields were also measured at both sites in 1990. At the treatment site, the ambient fields were measured during a maintenance period when the antennas were off. At the control site, ambient field measurements were made during normal antenna operation.

Three types of EM fields were characterized at each measurement point: transverse (or air) electric field, longitudinal (or earth) electric field, and magnetic flux density. For each of the fields, a set of orthogonal measurements were made and reduced to a single magnitude by vector addition. The EM field intensity measurement conditions are summarized below:

- 1) Ambient 60 Hz fields were measured at the control study site with both antennas operating at 150 amperes, standard phasing, and a modulated signal.
- 2) Ambient 60 Hz fields were measured at the treatment study sites while the antennas were off and connected in one of two standard configurations.
- 3) 76 Hz fields generated by the NRTF-Republic were measured with both antennas operating at 150 amperes, standard phasing, and a modulated signal.

### **60 Hz EM Fields**

60 Hz EM field measurement data for 1983 through 1990 are presented in Tables 2-4. Considerable year-to-year variability in these fields is evident. The primary factors in this variability at the treatment site are changes in powerline loading conditions (which are unknown) and differences in the configuration of the antennas at the time of measurement. Notes on the antenna configurations are included in the tables primarily for engineering use. The 60 Hz measurements at the treatment site in 1986, 1987, 1988 and 1990 were taken while the antennas were off, and are representative of 60 Hz levels present during maintenance periods. In 1989, measurements were taken at the treatment site during full power operation of the antennas with a non-modulated signal. These values indicate that 60 Hz EM fields present during operation of the antennas are comparable to those present when the antennas are off.

Annual variations in the 60 Hz fields measured at your control study site are also due to differences in powerline loading but have no dependence on the antenna configuration because of the distance of the site from the antennas. The 60 Hz field values at the control site, nonetheless, are about as variable as those at the treatment site.

Overall, the 60 Hz EM fields measured at both of your study sites in 1990 are consistent with previous field values and the expected differences in powerline loads and the antenna configuration. Regardless of the field variability associated with the measurement condition, 76 Hz EM fields at the treatment site consistently dominate the 60 Hz EM fields at both the treatment

and control sites and the ratio of 60 Hz EM fields between the treatment and control site continue to meet exposure criteria guidelines established at the beginning of the study.

### 76 Hz EM Exposures - 1990

The 76 Hz EM field measurement data taken during the 1990 annual EM survey, along with data from earlier years, are presented in Tables 5-7. All field measurements were made and are presented as vector sum magnitudes. The antenna currents at which measurements were made in each year are given in the column headings of the tables. The annual increases in field magnitudes reflect the level of antenna current at the time of measurement: 4 or 6 amperes in 1986, 15 amperes in 1987, 75 amperes in 1988, and 150 amperes in 1989 and 1990. The 1990 measurements are consistent with the 1989 measurements at the same current, and proportional to the 1986, 1987 and 1988 measurements made at lower currents.

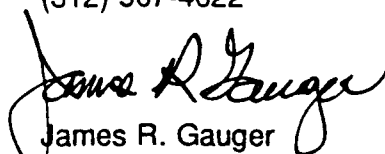
### 1991 Schedule

As an operational communications system, the MTF is expected to continue full-time 150 ampere operation except during scheduled maintenance periods. The annual EM measurements for 1991 have not been scheduled, but are likely to be in the June-October period. If you require any special engineering assistance or EM measurements in addition to those normally conducted or already discussed above, please inform us immediately so that these activities may be scheduled.

Sincerely,  
IIT RESEARCH INSTITUTE



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Research Engineer  
(312) 567-4622



James R. Gauger  
Engineering Advisor  
(312) 567-4480

cc: RDCarlson/File  
JEZapotosky  
RGDrexler

**TABLE 1. SITE NO. CROSS-REFERENCE**  
**Earthworms and Soil Arthropods Studies**

| IITRI<br>Site<br>No. | Investigator's<br>Site Name | Location |         |              |
|----------------------|-----------------------------|----------|---------|--------------|
|                      |                             | Township | : Range | : Section(s) |
| 3T2                  | South Silver Lake           | T44N     | : R29W  | : 25         |
| 3C5                  | Turner Road                 | T43N     | : R30W  | : 11         |

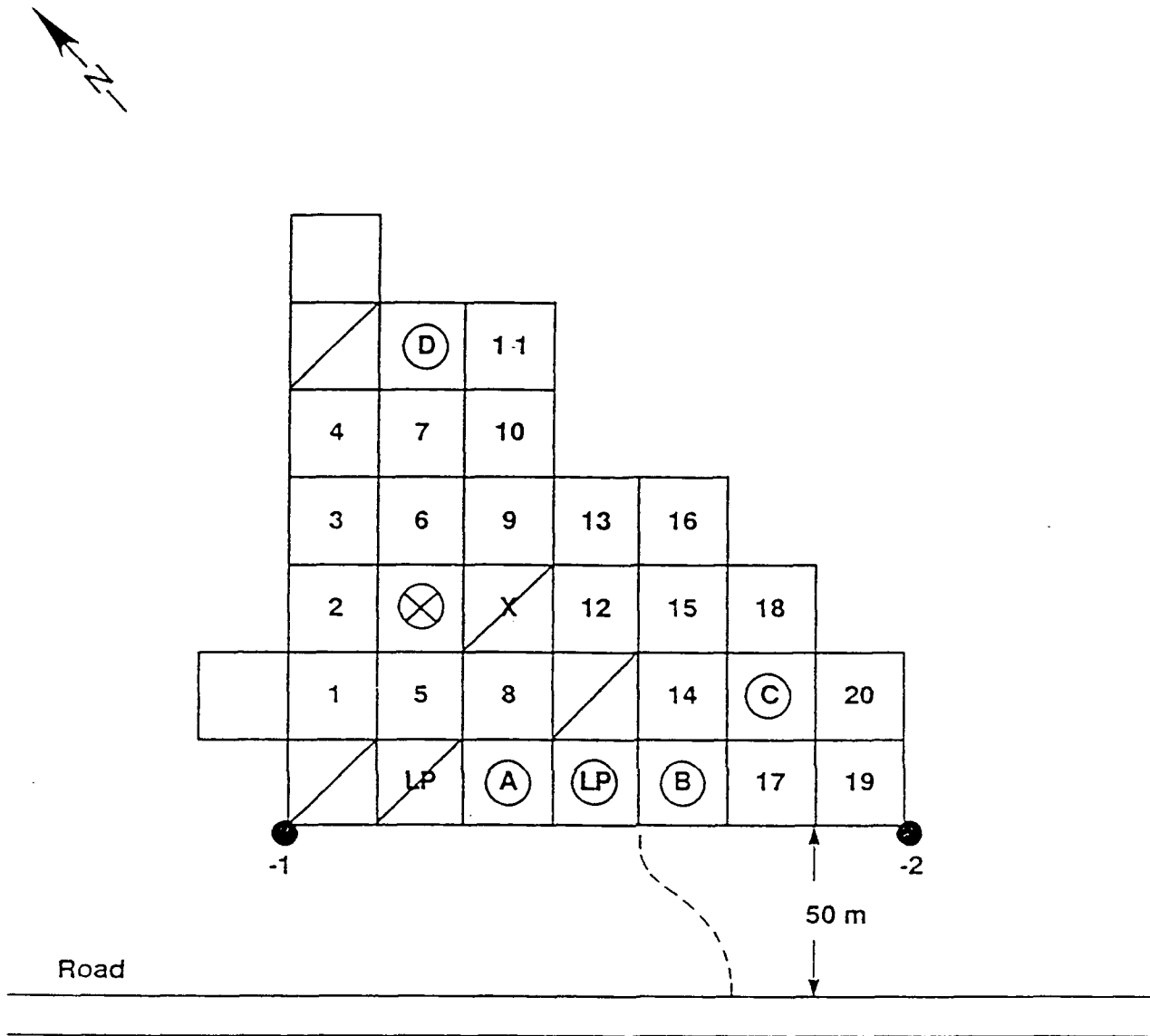


FIGURE 1. MEASUREMENT POINTS AT TURNER ROAD; 3C5-1, 2.





TABLE 2. 60 HZ TRANSVERSE ELECTRIC FIELD INTENSITIES (V/m)  
Soil Arthropods and Earthworms Studies

| Site No.,<br>Meas. Pt. | (a)<br>1983 | (a)<br>1984 | (a)<br>1985 | (b)<br>1986 | (c)<br>1987 | (c)<br>1988 | (d)<br>1989 | (d)<br>1990 |
|------------------------|-------------|-------------|-------------|-------------|-------------|-------------|-------------|-------------|
| 3C5-1                  | <0.001      | <0.001      | <           | <           | <           | <           | <           | < (d)       |
| 3C5-2                  | -           | -           | -           | <           | <           | <           | <           | < (d)       |
| 3T2-1                  | <0.001      | <0.001      | <           | <           | <           | <           | <0.001      | <0.001 (c)  |
| 3T2-2                  | -           | -           | -           | <           | <           | <           | <           | <0.001 (c)  |
| 3T2-3                  | -           | -           | -           | <           | <           | <           | <           | < (c)       |
| 3T2-4                  | -           | -           | -           | <           | <           | <           | <           | < (c)       |
| 3T2-5                  | -           | -           | -           | <           | <           | <           | <           | < (c)       |
| 3T2-6                  | -           | -           | -           | <           | <           | <           | <           | < (c)       |

a = antennas not constructed.

- = measurement point not established.

b = antennas off, grounded at transmitter.

< = measurement est. <0.001 V/m based on earth E-field.

c = antennas off, connected to transmitter.

d = antennas on, 150 A current.

TABLE 3. 60 Hz LONGITUDINAL ELECTRIC FIELD INTENSITIES (mV/m)  
Soil Arthropods and Earthworms Studies

| Site No.,<br>Meas. Pt. | (a)<br>1983 | (a)<br>1984  | (a)<br>1985 | (b)<br>1986 | (c)<br>1987 | (c)<br>1988 | (d)<br>1989 | (d)<br>1990 |
|------------------------|-------------|--------------|-------------|-------------|-------------|-------------|-------------|-------------|
| 3C5-1                  | 0.063       | 0.018, 0.032 | 0.036       | 0.027       | 0.054       | 0.054       | 0.062       | 0.065 (d)   |
| 3C5-2                  | -           | -            | -           | 0.027       | 0.071       | 0.085       | 0.182       | 0.118 (d)   |
| 3T2-1                  | 0.106       | 0.129, 0.27  | 0.194       | 0.045       | 0.042       | 0.091       | 0.055       | 0.042 (c)   |
| 3T2-2                  | -           | -            | -           | 0.068       | 0.049       | 0.093       | 0.049       | 0.043 (c)   |
| 3T2-3                  | -           | -            | -           | 0.038       | 0.043       | 0.084       | 0.035       | 0.047 (c)   |
| 3T2-4                  | -           | -            | -           | 0.045       | 0.039       | 0.087       | 0.068       | 0.040 (c)   |
| 3T2-5                  | -           | -            | -           | 0.044       | 0.045       | 0.084       | 0.053       | 0.047 (c)   |
| 3T2-6                  | -           | -            | -           | 0.048       | 0.033       | 0.087       | 0.041       | 0.042 (c)   |

a = antennas not constructed.

b = antennas off, grounded at transmitter.

c = antennas off, connected to transmitter.

d = antennas on, 150 A current.

- = measurement point not established.

TABLE 4. 60 HZ MAGNETIC FLUX DENSITIES (mG)  
Soil Arthropods and Earthworms Studies

| Site No.,<br>Meas. Pt. | 1983   | (a) | 1984   | (a) | 1985  | (a) | 1986   | (b) | 1987  | (c) | 1988  | (c) | 1989  | (d) | 1990      |
|------------------------|--------|-----|--------|-----|-------|-----|--------|-----|-------|-----|-------|-----|-------|-----|-----------|
| 3C5-1                  | 0.001  |     | 0.001  |     | 0.001 |     | 0.001  |     | 0.002 |     | 0.001 |     | 0.001 |     | 0.002 (d) |
| 3C5-2                  | -      |     | -      |     | -     |     | <0.001 |     | 0.001 |     | 0.001 |     | 0.002 |     | 0.001 (d) |
| 3T2-1                  | <0.001 |     | <0.001 |     | 0.001 |     | 0.005  |     | 0.002 |     | 0.004 |     | 0.001 |     | 0.003 (c) |
| 3T2-2                  | -      |     | -      |     | -     |     | 0.006  |     | 0.003 |     | 0.006 |     | 0.002 |     | 0.004 (c) |
| 3T2-3                  | -      |     | -      |     | -     |     | 0.004  |     | 0.003 |     | 0.003 |     | 0.001 |     | 0.003 (c) |
| 3T2-4                  | -      |     | -      |     | -     |     | 0.005  |     | 0.003 |     | 0.005 |     | 0.002 |     | 0.004 (c) |
| 3T2-5                  | -      |     | -      |     | -     |     | 0.005  |     | 0.003 |     | 0.004 |     | 0.002 |     | 0.004 (c) |
| 3T2-6                  | -      |     | -      |     | -     |     | 0.004  |     | 0.003 |     | 0.003 |     | 0.001 |     | 0.004 (c) |

a = antennas not constructed.

b = antennas off, grounded at transmitter.

c = antennas off, connected to transmitter.

d = antennas on, 150 A current.

- = measurement point not established.

TABLE 5. 76 Hz TRANSVERSE ELECTRIC FIELD INTENSITIES (V/m)  
Soil Arthropods and Earthworms Studies

| SITE NO.,<br>MEAS. PT. | 1986         |               |               | 1987                |               |               | 1988          |               | 1989          |               | 1990          |               |
|------------------------|--------------|---------------|---------------|---------------------|---------------|---------------|---------------|---------------|---------------|---------------|---------------|---------------|
|                        | NS<br>4 amps | NEW<br>6 amps | SEW<br>6 amps | SEW<br>10 amps (EX) | NS<br>15 amps | EW<br>15 amps | NS<br>75 amps | EW<br>75 amps | B<br>150 amps | B<br>150 amps | B<br>150 amps | B<br>150 amps |
| 3C5-1                  | <            | <             | <             | *                   | <             | <             | <             | <             | <             | <             | <             | <             |
| 3C5-2                  | <            | <             | <             | *                   | <             | <             | <             | <             | <             | <             | <             | <             |
| 312-1                  | 0.002        | <             | <             | *                   | 0.006         | <             | 0.031         | 0.003         | 0.064         | 0.056         |               |               |
| 312-2                  | 0.002        | <             | <             | *                   | 0.006         | <             | 0.024         | 0.003         | 0.070         | 0.068         |               |               |
| 312-3                  | 0.002        | <             | <             | *                   | 0.006         | <             | 0.028         | 0.003         | 0.048         | 0.067         |               |               |
| 312-4                  | 0.002        | <             | <             | *                   | 0.006         | <             | 0.026         | 0.003         | 0.055         | 0.061         |               |               |
| 312-5                  | 0.002        | <             | <             | *                   | 0.006         | <             | 0.029         | 0.005         | 0.061         | 0.056         |               |               |
| 312-6                  | 0.002        | <             | <             | *                   | 0.006         | <             | 0.027         | 0.002         | 0.048         | 0.055         |               |               |

NS = north-south antenna.

EW = east-west antenna.

NEW = northern EW antenna element.

SEW = southern EW antenna element.

B = NS + EW antennas, standard phasing.

EX = extrapolated data.

< = measurement est. <0.001 V/m based on earth E-field.

\* = data cannot be extrapolated.

TABLE 6. 76 Hz LONGITUDINAL ELECTRIC FIELD INTENSITIES (mV/m)  
Soil Arthropods and Earthworms Studies

| SITE NO.,<br>MEAS. PT. | 1986         |               |               |                     | 1987           |               |               |               | 1988          |               |                |               | 1989          |               | 1990          |               |
|------------------------|--------------|---------------|---------------|---------------------|----------------|---------------|---------------|---------------|---------------|---------------|----------------|---------------|---------------|---------------|---------------|---------------|
|                        | NS<br>4 amps | NEW<br>6 amps | SEW<br>6 amps | SEW<br>10 amps (EX) | SEW<br>15 amps | NS<br>15 amps | EW<br>15 amps | EW<br>75 amps | NS<br>75 amps | EW<br>75 amps | EW<br>150 amps | B<br>150 amps | B<br>150 amps | B<br>150 amps | B<br>150 amps | B<br>150 amps |
| 3C5-1                  | 0.005        | 0.001         | 0.002         | 0.003               | 0.020          | 0.034         | 0.006         | 0.093         | 0.093         | 0.027         | 0.22           | 0.21          |               |               |               |               |
| 3C5-2                  | 0.009        | 0.001         | 0.003         | 0.005               | 0.034          | 0.034         | 0.009         | 0.170         | 0.170         | 0.021         | 0.38           | 0.29          |               |               |               |               |
| 312-1                  | 1.33         | 0.057         | 0.188         | 0.31                | 5.4            | 5.4           | 0.54          | 27            | 27            | 2.6           | 58             | 55            |               |               |               |               |
| 312-2                  | 1.46         | 0.064         | 0.24          | 0.40                | 6.3            | 6.3           | 0.71          | 26            | 26            | 3.0           | 60             | 53            |               |               |               |               |
| 312-3                  | 1.19         | 0.047         | 0.149         | 0.25                | 5.3            | 5.3           | 0.60          | 27            | 27            | 2.7           | 49             | 56            |               |               |               |               |
| 312-4                  | 1.47         | 0.060         | 0.20          | 0.33                | 5.6            | 5.6           | 0.47          | 29            | 29            | 2.6           | 62             | 50            |               |               |               |               |
| 312-5                  | 1.56         | 0.070         | 0.23          | 0.38                | 5.7            | 5.7           | 0.61          | 27            | 27            | 2.8           | 52             | 59            |               |               |               |               |
| 312-6                  | 1.20         | 0.056         | 0.180         | 0.30                | 5.5            | 5.5           | 0.54          | 27            | 27            | 2.4           | 49             | 49            |               |               |               |               |

NS = north-south antenna.

EW = east-west antenna.

NEW = northern EW antenna element.

SEW = southern EW antenna element.

B = NS + EW antennas, standard phasing.

EX = extrapolated data.

TABLE 7. 76 Hz MAGNETIC FLUX DENSITIES (mG)  
Soil Arthropods and Earthworm Studies

| SITE NO.,<br>MEAS. PT. | 1986         |               |               |                     | 1987          |               | 1988          |               | 1989          |               | 1990          |               |
|------------------------|--------------|---------------|---------------|---------------------|---------------|---------------|---------------|---------------|---------------|---------------|---------------|---------------|
|                        | NS<br>4 amps | NEW<br>6 amps | SEW<br>6 amps | SEW<br>10 amps (EX) | NS<br>15 amps | EW<br>15 amps | NS<br>75 amps | EW<br>75 amps | B<br>150 amps | B<br>150 amps | B<br>150 amps | B<br>150 amps |
| 3C5-1                  | <0.001       | <0.001        | <0.001        | *                   | 0.002         | 0.001         | 0.008         | 0.003         | 0.019         | 0.018         |               |               |
| 3C5-2                  | <0.001       | <0.001        | <0.001        | *                   | 0.002         | 0.001         | 0.007         | 0.002         | 0.017         | 0.017         |               |               |
| 312-1                  | 0.048        | 0.001         | 0.001         | 0.002               | 0.187         | 0.003         | 0.88          | 0.012         | 1.84          | 1.81          |               |               |
| 312-2                  | 0.060        | 0.002         | 0.001         | 0.002               | 0.23          | 0.003         | 1.11          | 0.012         | 2.3           | 2.2           |               |               |
| 312-3                  | 0.046        | 0.001         | 0.001         | 0.002               | 0.182         | 0.002         | 0.89          | 0.012         | 1.81          | 1.80          |               |               |
| 312-4                  | 0.055        | 0.002         | 0.001         | 0.002               | 0.23          | 0.003         | 1.08          | 0.012         | 2.3           | 2.2           |               |               |
| 312-5                  | 0.057        | 0.002         | 0.001         | 0.002               | 0.22          | 0.003         | 1.03          | 0.012         | 2.2           | 2.1           |               |               |
| 312-6                  | 0.049        | 0.001         | 0.001         | 0.002               | 0.190         | 0.003         | 0.90          | 0.012         | 1.88          | 1.89          |               |               |

NS = north-south antenna.

EW = east-west antenna.

NEW = northern EW antenna element.

SEW = southern EW antenna element.

B = NS + EW antennas, standard phasing.

LX = extrapolated data.

\* = data cannot be extrapolated.

Michigan State University  
East Lansing, Michigan 48824-1115

SUBCONTRACT NUMBER  
EO 6595-88-C-005

ELF Communications System Ecological Monitoring Program

BIOLOGICAL STUDIES ON POLLINATING INSECTS: MEGACHILID  
BEES

Annual Report 1990

Karen Strickler  
J. Mark Scriber  
Department of Entomology





FRONTISPAGE

Subcontractor: Michigan State University  
East Lansing, Michigan 48824


Subcontract Number EO 6595-88-C-005

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Reporting year: 11/1/89 - 10/31/90

Prepared by Karen Strickler, Assistant Professor  
Principal Investigator  
Department of Entomology

Approved by:

  
Richard L. Howe, Asst. Director *sm*  
Contract and Grant Administration



## TABLE OF CONTENTS

|  |      |
|--|------|
| FRONTISPAGE.....                                   | iii  |
| LIST OF TABLES .....                               | vii  |
| LIST OF FIGURES .....                              | xi   |
| GLOSSARY AND LIST OF ACRONYMS .....                | xiii |
| I ABSTRACT .....                                   | 1    |
| II INTRODUCTION .....                              | 3    |
| Project Rationale and Overall Objectives. ....     | 3    |
| Nesting Biology of Megachilid Bees .....           | 4    |
| Hypotheses Tested .....                            | 7    |
| Hypotheses Involving Nest Architecture .....       | 7    |
| Hypotheses Involving Nest Activity .....           | 9    |
| Hypotheses Involving Emergence .....               | 10   |
| III METHODS AND TYPES OF DATA COLLECTED .....      | 11   |
| Trap Nesting Methodology .....                     | 11   |
| Nest Architecture Measurements .....               | 17   |
| Emergence Data .....                               | 18   |
| Leaf Counts .....                                  | 24   |
| Data Entry .....                                   | 24   |
| Nest Activity .....                                | 25   |
| Weather Data .....                                 | 26   |
| Description of sites .....                         | 27   |
| Floral Resource Levels .....                       | 29   |
| ELF Antenna Operations .....                       | 29   |
| Statistical Methods .....                          | 30   |
| IV NEST ARCHITECTURE RESULTS .....                 | 35   |
| Climate, Floral Resources, and Bee Abundance ..... | 35   |
| Hypothesis 1: Cell length, cells per nest .....    | 43   |
| <u>M. relativa</u> .....                           | 43   |
| <u>M. inermis</u> .....                            | 53   |
| Number of cells per nest .....                     | 72   |
| Hypothesis 2: Nest Plugs .....                     | 82   |
| Hypothesis 3: Leaves per nest .....                | 82   |
| Hypothesis 4: Nest orientation .....               | 83   |

|  |     |
|--|-----|
| V. NEST ACTIVITY RESULTS .....         | 97  |
| Hypothesis 5: LO trip durations .....  | 97  |
| VI EMERGENCE RESULTS .....             | 106 |
| Hypothesis 6: Prepupal mortality ..... | 106 |
| VII SUMMARY .....                      | 137 |
| VIII REFERENCES .....                  | 141 |

## LIST OF TABLES

|  |    |
|--|----|
| TABLE 1: Diameter of drill bits used to create trap nests .....  | 12 |
| TABLE 2: Time line of ELF antenna operations, nest construction<br>and overwintering, and data analyses .....  | 31 |
| TABLE 3: Number of nests of <u>M. relativa</u> and <u>M. inermis</u> at each<br>site for which we have data on complete cell lengths.<br>.....                                     | 36 |
| TABLE 4: GLM of mean cell length for all cells from 1985-1989 <u>M.</u><br><u>relativa</u> nests.....  | 45 |
| TABLE 5: GLM of mean cell lengths for 1985 - 1989 <u>M. relativa</u><br>nests; cells expected to have female offspring. ....   | 48 |
| TABLE 6: GLM of mean cell lengths for 1985 - 1989 <u>M. relativa</u><br>nests; cells expected to have male offspring. ....   | 49 |
| TABLE 7: <u>M. relativa</u> secondary sex ratio by site and year. ....   | 50 |
| TABLE 8: <u>M. relativa</u> primary sex ratio by site and year. ....   | 51 |
| TABLE 9: Differences between observers in mean cell lengths for<br><u>M. relativa</u> .....  | 52 |
| TABLE 10: Two-Way, Model II ANOVA partitioning the<br>variance in cell length within- and between- measurer. ....  | 54 |
| TABLE 11: GLM of mean cell lengths for <u>M. inermis</u> nests: cells<br>expected to have female offspring; pooled preoperational vs.<br>operational years; diameters >9.5mm. .... | 56 |
| TABLE 12: GLM of mean cell lengths for <u>M. inermis</u> nests: cells<br>expected to have male offspring; pooled preoperational vs.<br>operational years; diameters >9.5mm. ....   | 58 |
| TABLE 13: Differences between observers in mean male cell<br>lengths for <u>M. inermis</u> ; bore diameters >9.5. ....   | 61 |
| TABLE 14: <u>M. inermis</u> secondary sex ratio by site and year. ....   | 62 |
| TABLE 15: <u>M. inermis</u> primary sex ratio by site and year. ....   | 63 |
| TABLE 16: <u>M. relativa</u> weights by sex, site, and year.....   | 68 |
| TABLE 17: <u>M. inermis</u> weights by sex, site and year.....   | 70 |
| TABLE 18: Categorical modeling of number of cells per complete<br>nest of <u>Megachile relativa</u> , 1985-1989.....   | 74 |
| TABLE 19: Categorical modeling of number of cells per complete<br>nest of <u>Megachile relativa</u> by season; 1985-1989; diameters<br>>9.5mm; bore depths >135mm.....             | 76 |
| TABLE 20: Categorical modeling of number of cells per complete<br>nest of <u>Megachile inermis</u> ; 1985-1989; diameters >9.5mm; bore<br>depths >135mm. ....                      | 79 |
| TABLE 21: Categorical modeling of number of cells per complete<br>nest of <u>Megachile inermis</u> by season; 1987+1989; diameters<br>>9.5mm; bore depths >135mm. ....             | 81 |

|  |     |
|--|-----|
| TABLE 22: GLM of mean of ln transformed leaves per cell in <u>M. inermis</u> nests: Cells expected to have female offspring; pooled preoperational vs. operational years; diameters >9.5mm. .... | 86  |
| TABLE 23: GLM of mean of ln transformed leaves per cell in <u>M. inermis</u> nests: Cells expected to have male offspring; pooled preoperational vs. operational years; diameters >9.5mm. ....   | 88  |
| TABLE 24: Chi-Square heterogeneity Goodness of Fit analysis of <u>M. relativa</u> nest orientation by hutch set and year. ....   | 92  |
| TABLE 25: Log-likelihood ratio heterogeneity contingency tables for <u>M. relativa</u> nest entrance orientation by hutch set and year. ....   | 94  |
| TABLE 26: GLM of mean of log log transformed LO trip durations; trips 1-3 for each timed <u>M. inermis</u> ; 1987-1990. ....   | 99  |
| TABLE 27: GLM of ln ln transformed LO trip durations for <u>M. inermis</u> ; 1987; trips 1-8. ....   | 102 |
| TABLE 28: GLM of ln ln transformed LO trip durations for <u>M. inermis</u> ; 1988; trips 1-8. ....   | 103 |
| TABLE 29: GLM of ln ln transformed LO trip durations for <u>M. inermis</u> ; 1989; trips 1-8. ....   | 104 |
| TABLE 30: GLM of ln ln transformed LO trip durations for <u>M. inermis</u> ; 1990; trips 1-8. ....   | 105 |
| TABLE 31: Late summer emergences (% bivoltinism) of <u>M. relativa</u> and <u>Coelioxys moesta</u> . ....  | 107 |
| TABLE 32: Late summer emergences (% bivoltinism) of <u>M. inermis</u> and <u>Coelioxys</u> spp. ....   | 108 |
| TABLE 33: Proportion of <u>M. relativa</u> mortality from various sources by site. ....  | 110 |
| TABLE 34: Proportion of <u>M. inermis</u> mortality from various sources by site. ....   | 113 |
| TABLE 35: ANOVA of Freeman-Tukey arcsine transformed proportion of cells with prepupal mortality for <u>M. relativa</u> , 1985 - 1989. ....  | 121 |
| TABLE 36: Multiple comparison tests for differences between years in the proportion of cells with prepupal mortality for <u>M. relativa</u> , 1985-1989. ....                                    | 121 |
| TABLE 37: ANOVA of Freeman-Tukey arcsine transformed proportion of cells with prepupal mortality for <u>M. inermis</u> , 1985 - 1989. ....   | 123 |
| TABLE 38: Multiple comparison tests for differences between years in the proportion of cells with prepupal mortality for <u>M. inermis</u> 1985-1988. ....                                       | 123 |
| TABLE 39: ANOVA of Freeman-Tukey arcsine transformed proportion of nests with prepupal mortality for <u>M. relativa</u> , 1985 - 1989. ....  | 125 |

|   |     |
|---|-----|
| TABLE 40: Multiple comparison tests for differences between years in the proportion of nests with prepupal mortality for <u>M. relativa</u> 1985-1988.....      | 125 |
| TABLE 41: ANOVA of Freeman-Tukey arcsine transformed proportion of nests with prepupal mortality for <u>M. inermis</u> , 1985 - 1989.....                       | 127 |
| TABLE 42: Multiple comparison tests for differences between years in the proportion of nests with prepupal mortality for <u>M. inermis</u> 1985-1988.....       | 127 |
| TABLE 43: ANOVA of Freeman-Tukey arcsine transformed proportion of cells with prepupal mortality for <u>M. relativa</u> , 1988 - 1989; direction included. .... | 130 |
| TABLE 44: ANOVA of Freeman-Tukey arcsine transformed proportion of cells with prepupal mortality for <u>M. inermis</u> , 1988 - 1989; direction included. ....  | 132 |
| TABLE 45: ANOVA of Freeman-Tukey arcsine transformed proportion of nests with prepupal mortality for <u>M. relativa</u> , 1988 - 1989; direction included. .... | 134 |
| TABLE 46: ANOVA of Freeman-Tukey arcsine transformed proportion of nests with prepupal mortality for <u>M. inermis</u> , 1988 - 1989; direction included. ....  | 136 |





## LIST OF FIGURES

|  |     |
|--|-----|
| FIGURE 1. Cut away view of a completed <u>Megachile</u> nest. .  | 5   |
| FIGURE 2. Example of arrangement of nests in block, 1983 - 1986. ....  | 13  |
| FIGURE 3. Example of arrangement of nests in block, 1987. ....   | 14  |
| FIGURE 4. Hutch, with one block of nests. ....   | 16  |
| FIGURE 5. A single reproductive cell, indicating how cell lengths<br>are measured. ....  | 19  |
| FIGURE 6a, b. Wire mesh Faraday cages, used to reduce exposure<br>of nests to 60hz EM fields while nest architecture<br>measurements are made in Crystal Falls. .... | 21  |
| FIGURE 7. Wire mesh Faraday cage on front porch in Crystal<br>Falls, used to store nests and cells just before and after nest<br>measurements are made. ....         | 22  |
| FIGURE 8. Number of nests of <u>Megachile relativa</u> constructed at<br>four sites, 1985-1990. ....   | 37  |
| FIGURE 9. Number of nests of <u>Megachile inermis</u> constructed at<br>four sites, 1985-1990. ....  | 38  |
| FIGURE 10. Cumulative precipitation at MTU pine plantations. ....  | 39  |
| FIGURE 11. Cumulative number of nests of <u>M. relativa</u> and <u>M.</u><br><u>inermis</u> at each site, 1985-1989. ....  | 41  |
| FIGURE 12. Mean cell length for <u>M. relativa</u> nests, 1985-1989, all<br>cells. ....  | 44  |
| FIGURE 13. Mean cell length for <u>M. inermis</u> nests, diameters<br>>9.5mm. ....   | 55  |
| FIGURE 14. Male <u>M. inermis</u> dry weight vs. cell length, 1988. ....   | 64  |
| FIGURE 15. Male <u>M. inermis</u> dry weight vs. cell volume, 1988. ....   | 65  |
| FIGURE 16. Male <u>M. inermis</u> live weight vs. cell length, 1988. ....  | 66  |
| FIGURE 17. Male <u>M. inermis</u> live weight vs. cell volume, 1988. ....  | 67  |
| FIGURE 18. Number of complete nests of <u>M. relativa</u> with 1-2, 3-<br>4, 5-6 or 7+ cells. ....   | 73  |
| FIGURE 19. Number of complete nests of <u>M. relativa</u> with few (1-<br>4) or many (5-12) cells, separated by season. ....   | 75  |
| FIGURE 20. Number of complete nests of <u>M. inermis</u> with few (1-<br>4) or many (5-8) cells. ....  | 78  |
| FIGURE 21. Number of complete nests of <u>M. inermis</u> with few (1-<br>4) or many (5-8) cells, separated by season. ....   | 80  |
| FIGURE 22: Distribution of nest plug lengths for <u>M. inermis</u> , 1985<br>nests. ....   | 84  |
| FIGURE 23. Mean leaves per cell for <u>M. inermis</u> nests, diameters<br>>9.5mm. ....   | 85  |
| FIGURE 24. Mean duration of LO collecting trips for the first<br>three leaf collecting trips in a cell cap. ....   | 98  |
| FIGURE 25. Duration of LO collecting trips based on analysis of<br>first eight trips; nest number included as a class variable. ....                                 | 101 |

|   |     |
|---|-----|
| FIGURE 26. Proportion of mortality from various sources by site,<br><u>M. relativa</u> .                                  | 109 |
| FIGURE 27. Proportion of mortality from various sources by site,<br><u>M. inermis</u> .                                   | 112 |
| FIGURE 28. Phenology of emergence, 1987 nests emerging in<br>1988.  | 116 |
| FIGURE 29. Phenology of emergence, 1988 nests emerging in<br>1989.  | 117 |
| FIGURE 30. Phenology of emergence, 1989 nests emerging in<br>1990.  | 118 |
| FIGURE 31. Percent of cells with prepupal mortality by year and<br>site, <u>M. relativa</u> .                             | 120 |
| FIGURE 32. Percent of cells with prepupal mortality by year and<br>site, <u>M. inermis</u> .                              | 122 |
| FIGURE 33. Percent of nests with prepupal mortality by year and<br>site, <u>M. relativa</u> .                             | 124 |
| FIGURE 34. Percent of nests with prepupal mortality by year and<br>site, <u>M. inermis</u> .                              | 126 |
| FIGURE 35. Percent of cells with prepupal mortality by year, site,<br>and nest entrance orientation, <u>M. relativa</u> . | 129 |
| FIGURE 36. Percent of cells with prepupal mortality by year, site,<br>and nest entrance orientation, <u>M. inermis</u> .  | 131 |
| FIGURE 37. Percent of nests with prepupal mortality by year, site,<br>and nest entrance orientation, <u>M. relativa</u> . | 133 |
| FIGURE 38. Percent of nests with prepupal mortality by year, site,<br>and nest entrance orientation, <u>M. inermis</u> .  | 135 |

## GLOSSARY AND LIST OF ACRONYMS

**C5:** Camp 5 control site

**CATMOD:** Categorical data modeling procedure in SAS.

**CL:** County Line control site

**ELF:** Extremely Low Frequency

**EM:** Electromagnetic

**Exp:** Variable indicating whether the data were from an experimental or a control area.

**Exp\*Year:** Interaction effect of the Exp and year variables in the GLM, ANOVA, or CATMOD model.

**Expected Sex:** The actual or predicted sex of the bee offspring in a cell. Predicted sex is based on the order of the cell in the nest, and the presence of at least one cell of known sex. Females are found in the innermost cells, males in the outermost cells (see p. 14, 16).

**F1:** Ford 1 (north Ford) experimental site

**F2:** Ford 2 (south Ford) experimental site

**GLM:** General Linear Modeling procedure in SAS.

**LO:** A round leaf piece used to cap a cell, plug a nest, or occasionally at the base of a cell. Occasionally an LO will be part of the construction of a cell lining as well as LRs. The bee carries an LO in her mandibles.

**LR:** An elongate, oblong leaf piece used to line a cell. The bee carries an LR rolled between her legs.

**Measurer:** Variable indicating the person who observed or measured data.

**Primary sex ratio:** The sex ratio that would have been produced if all cells had yielded an offspring.

**SAS;** Statistical software package on the VAX computer, used in analysis of data.

**Season (early vs. late):** Nests were classified as "early season" if they were begun on or before the date on which half of the nests of that species were begun at that site during that year. Nests begun on later dates were classified as "late season" nests.

**Secondary sex ratio:** The ratio of male to female adult and pupal offspring, which could be sexed with certainty.

**Site [exp]:** Site variable nested in experimental areas.

**Trip Rank:** The number of LO leaves already collected by a bee, including the current LO, in a series of LO trips to cap a cell. Usually the duration of the first 5 such trips are recorded for a given cell cap. These LO trip durations are given Trip Ranks of 1,2,3,4, and 5 respectively.

**Yr:** Year

## I ABSTRACT

High voltage transmission lines and magnetic fields have been shown to affect honeybee reproduction, survival, orientation, and nest structure. ELF EM fields could have similar effects on native megachilid bees.

Two species in the genus Megachile have been abundant in artificial nests at experimental and control sites in Dickinson and Iron Counties in Michigan. Data on their nest architecture, nest activity, and emergence/mortality have been collected since 1983. Five hypotheses concerning the possible effects of ELF EM fields are considered using these data. The ELF ANTENNA has been at 100% power since the summer of 1989. Exposure to ELF EM fields could be reflected in nest activity data for 1989 and 1990, and in nest architecture and mortality for nests constructed in 1989.

Our hypotheses have involved monitoring changes in cell length, number of cells per nest, number of leaves per cell, orientation of nest entrances, and time to collect a round leaf piece to cap a cell. Thus far during operational years we have not detected significant changes at experimental areas that could be attributed to ELF EM fields. Data will continue to be collected and analyzed for two more years to determine whether additional years of exposure reveal effects not detected after a single season.

One possible effect of ELF EM fields was detected in last year's analysis. M. inermis prepupal (overwintering) mortality in nests oriented along a NS axis was lower in experimental than in control areas for 1988 nests. 1988 was the first year with significant testing of the antenna during the winter, and the first year that the nests were overwintered in the direction that they were constructed. This effect was not observed for 1989 prepupal mortality, suggesting that the pattern observed in 1988 was unrelated to ELF EM fields. However, high prepupal mortality due to cool spring temperatures in 1990 may be masking any effects that ELF EM fields have during the winter.

An experiment was begun in 1990 in which a sample of nests from one of the experimental sites is overwintering at one of the control sites. We hope that results of this experiment will help determine whether ELF EM fields affect overwintering mortality.



## II INTRODUCTION

### **Project Rationale and Overall Objectives.**

High voltage transmission lines and fluctuations in the earth's magnetic field have been reported to affect honeybees (Greenberg et al. 1981a,b; Gould 1980). In addition, honeybees have been shown to have an organ in the abdomen consisting of magnetite particles that could be used to detect the earth's magnetic field and thus could be used as a compass in orientation (Gould et al. 1978). This organ appears to be involved in the detection by foraging honeybees of localized magnetic anomalies associated with nectar rewards (Walker and Bitterman, 1989). Honeybees appears to use the earth's magnetic field as a reference system for orientation based on polarized light, and the presence of an artificial magnetic field causes a positive deviation in the angle of the waggle dance for bees orienting thieir dance on a horizontal hive where skylight but not the sun is visible (Leucht and Martin, 1990). Because such effects of electric and magnetic fields have been demonstrated, it is possible that ELF EM fields may alter a bee's ability to orient or may otherwise affect its behavior.

Honeybees, however, are rare in the state forest where the Michigan ELF antenna is located (personal observation), and are unable to overwinter in the harsh climate of Michigan's Upper Peninsula (Fischer, 1983 Annual Report). Therefore, native bees are a better choice for ecological studies of the resident bee fauna. Native bees are particularly important in ecological communities such as those in the vicinity of the ELF antenna because they are pollinators of flowering plants, and are therefore important to the reproductive success of these plants.

With the exception of bumblebees and some halictids, native bees are solitary, meaning that each female constructs and provisions her own nest rather than having a special queen caste responsible for reproduction. Solitary bees have several advantages for ecological studies. As "mass provisioners", they create a discrete cell for each offspring, and fill it with a provision mass of pollen and nectar prior to laying the egg. The bee does not add more provisions after the egg is laid. A series of such cells, each with a provision mass and egg, are created in succession by each female. The provisions that go into each cell are a direct measure of parental investment in an offspring (Strickler 1979; Cowan 1981; Johnson 1983; Danforth 1990). The size of the adult bee that emerges from each cell is correlated with the amount of provisions provided it, and with the size of the cell in which the larva develops (Krombein 1967; Klostermeyer et al. 1973; Trivers and Hare 1976; Alcock 1979; Torchio and Tepedino 1980;

Johnson 1983; Danforth 1990). However, there is a tradeoff between the investment per offspring and the rate at which offspring are produced. The more the bee invests per offspring (ie, the larger the offspring), the fewer offspring she will produce. If bees are disoriented, agitated, or slower at foraging, they may invest less per offspring, produce fewer offspring per unit time, or both. Solitary bees are unusual in having this direct relationship between parental investment per offspring, adult size, and reproductive output.

The nesting biology of some species of solitary bees in the family Megachilidae is especially easy to study because they accept artificial nests placed in the field. These bees typically nest in abandoned beetle bores in dead logs. "Trap nests" of drilled blocks of wood are also used by bees as nest sites. Such artificial nests can be placed in habitats where bees are expected to nest, in order to increase the sample of nests available for study, and to standardize such characteristics of the nest as bore depth and diameter (Krombein, 1967). Trap nests are used in the management of the Alfalfa Leafcutter Bee, Megachile rotundata, for pollination of alfalfa (Stephen, 1962; Bohart and Knowlton, 1964; Johansen et al., 1969; Gerber and Klostermeyer, 1972; Hobbs, 1972), and the Blue Orchard Bee, Osmia lignaria for the pollination of fruit trees (Torchio 1981a,b; 1982a,b,c; 1984a,b; 1985). Thus there is an extensive (though largely unreviewed) literature on megachilid biology.

Research on the effects of high tension wires and magnetic fields on honeybees suggests working hypotheses on which to base our analyses of megachilid nesting biology. Of possible relevance to megachilid behavior are an alleged greater tendency for dispersal, and greater levels of activity (Wellenstein, 1973), as well as reduced reproductive output, lower overwintering survival, and modifications of nest structure (Greenberg et al., 1981) when colonies were exposed to electromagnetic fields from high voltage transmission lines. Disturbance of colonies under transmission lines can be attributed to electric shock from induced hive currents, especially under wet conditions (Bindokas et al., 1988). In addition, disorientation due to fluctuations in ELF magnetic fields is possible if megachilids share the honeybee's ability to detect magnetic fields. (Gould et al., 1978, 1980; Gould 1980; Tomlinson et al. 1981; Walker and Bitterman, 1989).

### Nesting Biology of Megachilid Bees

A decision to restrict our study to two species of leaf-cutter bees, Megachile (Megachile) relativa Cresson and Megachile (Megachile) inermis Provancher, was made in the fall of 1986 (1986 Annual Report). M. inermis and M. relativa have similar nest architecture in that both line their cells with pieces of cut leaves. However, the two species differ in



size, and may therefore partition their time and the space in their nests differently. Aspects of the biology of both species have been described generally for populations in Wisconsin and Canada (Medler, 1958; Medler and Koerber, 1958; Stephen, 1955,1956; Longair, 1981).

The general structure of the nests of the two species is depicted in Fig. 1. The bee may leave some space at the base of the nest (the basal space) unoccupied by cells for offspring. She may then cut and bring to the nest a few

round pieces of leaf that are added one at a time to form the base of the first cell. Next she cuts and brings to the nest several elongate pieces of leaf (LRs) in succession. These are used to line a tube- or cup-shaped cell that is slightly longer than her body. Next she makes a series of pollen and nectar foraging trips to fill the cell with the discrete provision mass that will be the larva's food supply. When provisioning is complete, the female lays an egg. Fertilized eggs become females while unfertilized eggs become males. The female has voluntary control over fertilization and thus the sex of the offspring in each cell (Klostermeyer and Gerber, 1970). After laying the egg, she cuts more leaves, this time round in shape (LOs), to cap the cell. Sometimes she adds chewed leaves, sand, or bits of wood to separate the cells. Next she cuts more elongate leaves for the second cell, and repeats the process. Thus a linear series of cells is constructed in the nest bore. Typically, the cells at the base of the nest are more likely to contain females and the cells near the entrance are more likely to contain males (Krombein, 1967). Since females are usually larger than males in these bees, cells at the base of the nest tend to be larger than cells near the entrance. When she has completed the last cell that she is going to put in the nest, she constructs a series of plugs of round leaves, chewed leaves, dirt, chewed wood, and possibly other material. M. relativa frequently includes empty "vestibular" spaces between segments of plug. M. inermis and some M. relativa create one long mass of plug material after completing the reproductive cells. In nests of both species there may also be space between the outermost plug and the opening of the nest, called an "indentation".

Each female may construct several such nests over her life time. Some nests are abandoned before they are finished because the bee has died, or for other unknown reasons. The adult life span is no more than one season; adults do not overwinter.

Inside each cell the egg hatches, and the young larva feeds on the provisions prepared by its mother. Both Megachile species in our study are univoltine in Northern Michigan (with a few exceptions; see

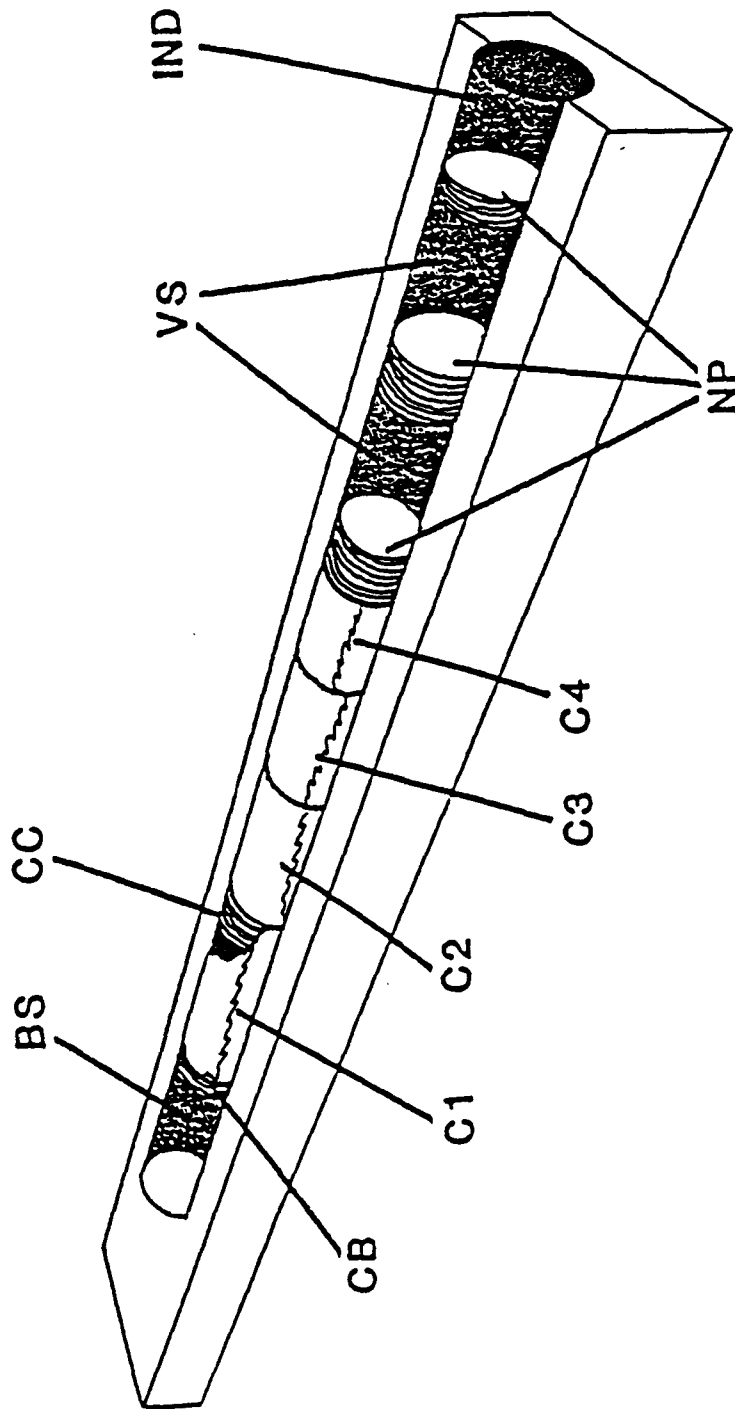


FIGURE 1. Cut away view of a completed Megachile nest.

BS - Basal Space; CB - Cell Base; C1, C2, C3, C4 - Reproductive Cells 1 through 4; CC - Cell Cap;  
NP - Nest Plugs; VS - Vestibular Spaces; IND - Indentation.

Emergence Results), and both overwinter as prepupae. Pupation occurs in Spring, and adults emerge soon after, in June and July at our study sites. A variety of parasites may emerge from the cell instead of the original bee. Oviposition of parasite eggs usually occurs while the cell is being provisioned, when the mother bee is out of the nest on a pollen foraging trip, or on a round-leaf foraging trip just after laying her egg.

### Hypotheses Tested

During the first four years of the project, 1983-1986, data on nest architecture, nest orientation, emergence/mortality and nest activity were collected. Based on these data, six tentative hypotheses concerning the effects of ELF EM fields on Megachile behavior were specified in the 1986 Annual Report. The initial hypotheses were modified in previous reports based on our ability to gather sufficient sample sizes to detect differences between experimental and control areas. The modified hypotheses are expressed in the following sections as null hypotheses, ie., hypotheses of no difference between experimental and control areas, that we will try to disprove statistically. The "Rationale" sections explain the possible effects of ELF EM fields that may cause a rejection of the null hypothesis.

#### Hypotheses Involving Nest Architecture:

**Hypothesis 1:** The average size (length and volume) of cells for each offspring, and/or the average number of cells produced per nest is unchanged by exposure to ELF electromagnetic fields.

#### Rationale

Honeybee reproductive output decreased on exposure to high voltage transmission lines. Capped brood, which normally averaged 12,000 per hive, decreased to as low as no brood after 8 weeks of exposure (Greenberg, et al., 1981b). ELF EM fields may have a similar effect on the number of cells produced by megachilids. Furthermore, ELF electromagnetic fields may affect cell size and nest architecture in various ways. For example, if bees are disoriented by the fields, they may gather resources (leaves, pollen) more slowly when exposed to the fields than when not exposed. As a result, they may produce new cells at a slower rate, or they may produce smaller cells.

Previous studies have found that the weight of offspring of the generalist megachilids, Osmia lignaria and O. cornifrons, is lower if their cells were produced late in the season rather than early in the season (Torchio and Tepedino, 1980; Sugiura and Maeta, 1989). These species also showed an increase in the proportion of male offspring (the smaller sex).

produced late in the season. A reduction in offspring size late in the season is related to reduced foraging rates due to aging of the bee (Torchio and Tepedino, 1980, Tepedino and Torchio, 1982; Sugiura and Maeta, 1989). Similarly, ELF EM fields may slow the foraging of M. relativa and M. inermis, resulting in smaller bees produced in smaller cells. A size reduction could affect cells with offspring of both sexes, or it could reflect the production of a greater proportion of male offspring, since males are the smaller sex in both Megachile species. An additional complication is that female sizes decrease more than male sizes late in the season (Torchio and Tepedino, 1980). Thus we might expect female cells to be affected more than male cells by stresses from ELF EM fields.

In contrast to the generalist megachilids, the pollen specialist Hoplitis anthocopoides did not show a reduction in offspring weight late in the season, in spite of reduced foraging rates (Strickler, 1982). Rather, it was hypothesized that slower foraging rates led to fewer offspring per nest late in the season as compared with early in the season for this species. Similarly, M. relativa and M. inermis may produce fewer cells per nest in response to slow foraging rates due to ELF EM fields.

In testing hypothesis 1 we are interested in determining whether there are differences between experimental and control sites in cell lengths, cell volumes, and number of cells per nest. Ideally, we hope to find no differences between experimental and control sites, and between years, prior to the 1987 season when the ELF antenna was operational at low power. Then, if significant differences between experimental and control sites appear in the years after the antenna is turned on, we can attribute these differences to the effect of ELF EM fields.

**Hypothesis 2:** Bees exposed to ELF EM fields, and bees not exposed, will make nest plugs of the same thickness and will devote the same proportion of nest space to reproduction.

### Rationale

Abnormal deposits of up to 48g of propolis were present at honeybee hive entrances under high voltage transmission lines, presumably in response to stress connected with electric fields at the nest entrance (Greenberg et al, 1981b). This suggests the possibility that megachilid bees will respond to disturbance from ELF EM fields by increasing the amount of nest lining material in the bores. This may be reflected in larger cells (tested in hypothesis 1) and/or increased nest plug length. More generally, there could be an increase in the nest space that does not include cells for offspring (ie. basal and vestibular spaces, nest plugs and indentations).

**Hypothesis 3:** The number of leaves used to line a cell is unchanged when bees are exposed to ELF EM fields.

**Rationale**

Bees may pad a cell with extra leaves as a result of stress due to electromagnetic fields, just as they may pad a nest with plug material. We can easily determine the number of elongate leaves used to line a cell by taking the cell apart after bee emergence and counting leaves.

**Hypothesis 4:** The relative acceptability of nests oriented in a NS direction vs. nests oriented in an EW direction does not change when bees are exposed to ELF EM fields.

**Rationale**

Honeybees may use the earth's magnetic field under special circumstances to orient their comb (reviewed in Gould, 1980). The fluctuating ELF magnetic fields could disturb any biases that megachilids normally have for nest orientation, or could cause greater acceptance of nests oriented in certain directions in order to reduce disturbance by the fields.

**Hypotheses Involving Nest Activity**

**Hypothesis 5:** The duration of round leaf (LO) foraging trips remains the same when bees are exposed to ELF EM fields.

**Rationale**

Honeybee activity, measured by honey production, allegedly doubled under high voltage electromagnetic fields in one study (Wellenstein, 1973). In contrast, colony weight, a measure of rate of honey accumulation and brood production, decreased by as much as half for colonies exposed to high voltage transmission lines in a different study (Greenberg et al., 1981b). In a third study, there were dose-related lags in colony weight gain, with the maximum difference being a doubling of exposed hive weights compared with more than a six fold increase in control colonies in 5 weeks (Greenberg, 1981a). Foraging rates were decreased by as much as half in exposed colonies in this study (Greenberg, 1981a). Honeybees also had an increased tendency to sting under high voltage transmission lines (Wellenstein, 1973) and when exposed to high voltage EM fields in the laboratory (Bindokas et al., 1989). ELF EM fields might similarly affect megachilid bee activity by disorienting or agitating the bees so that the

duration of leaf- and pollen-foraging trips is altered. Interference with magnetoreception might play a role in disorientation. Changes in electric potential of the bees, or of the plants on which they forage (Erickson, 1975), or changes in the electrical potential of antennal chemosensilla that detect plant odors (Erickson, 1982), might also affect the bees' foraging rate.

Leaf-foraging trips for M. inermis are easy to recognize behaviors, usually lasting less than a minute in duration. Many of these trips are taken in succession, so within and between bee variability can be analyzed, and a potentially large sample of leaf collecting trips can be timed. In the 1986 Annual Report we demonstrated that the collection of LO leaves was the most consistent behavior of the leaf-cutting bees under study. We argued that this is probably because it is adaptive to close the cell as quickly as possible after the egg is laid to avoid parasitism. Thus, our analysis focuses on LO trip durations.

### **Hypotheses Involving Emergence:**

**Hypothesis 6:** Overwintering mortality of megachilid bees is unchanged by exposure to ELF EM fields.

### **Rationale**

Overwintering mortality of honeybee colonies under high voltage transmission lines increased from 29% when hives were shielded to 71% when they were fully exposed to electrical fields. (Greenberg et al., 1981b). We would like to test for a similar effect in megachilid bees. To do this requires comparing control and experimental sites in the proportion of cells that suffer mortality during the prepupal (overwintering) stage, relative to the number of cells that survive to the prepupal stage or beyond (pupa and adult) (see results section for further explanation).

According to Brodeur (1989, p.58), studies of the effects of ELF EM fields on chicken embryos suggest that teratological effects depend on the orientation of the embryo relative to both an artificially pulsed field and the earth's magnetic field. I have not found an original reference for this result, although Leal et al. (1986) and Berman (1990) imply that such a relationship may be important. However if true, this suggests that overwintering mortality (as well as mortality of eggs and developing larvae) may be different for nests oriented in a north-south vs. nests oriented in an east-west direction.

### III METHODS AND TYPES OF DATA COLLECTED

Nest architecture and nest orientation are obtained by placing trap nests in the environment, and allowing bees to construct nests in their choice of traps during the summer. The following spring, various parameters of their nest architecture are measured. Bee and parasite emergence and larval and pupal mortality are also recorded in the Spring. Nest activity data are gathered during the summer season while the bees are constructing their nests.

The methods discussed below will compare, where appropriate, changes in protocol over the years, especially pre- and post-1987. Where no such comparisons have been made, no significant changes in protocol have been made.

#### Trap Nesting Methodology

Trap nests consist of elongate white pine pieces 19x19x153 mm. Most of these nests were drilled lengthwise to a depth of 142mm. Exceptions were the largest diameter nests pre-1987, and half of the 1987 large diameter nests. These nests were drilled to only 107mm.

Prior to 1987, drill bits with seven different diameters were used to create trap nests (Table 1). The maximum diameter was limited by the dimensions of the trap nest, and by availability of long drill bits.

In 1987 only the 5.5mm bit and the 11.0mm bit were used because these diameters were accepted most often in 1985 by the two Megachile species under study (see 1986 annual report). In 1988-1990 small nests were made with both 5.5 and 6.0mm drill bits because analysis of 1986 nests indicated that the 6.0 mm diameters were common, and because it was feared that 5.5 mm diameters would skew the sex ratio in favor of male offspring and thus bias the cells towards shorter lengths. Bore diameter has been shown to influence sex ratio for other trap nesting species (Stephen and Osgood, 1965; Krombein, 1967; Cowan, 1981; Tepedino and Torchio, 1989).

In 1985 and 1986, twelve nests, two of each bore diameter, were bound together with plastic strapping into a "block", so that one of each bore diameter faced each direction, and no two bore entrances were adjoining (Fig. 2). Starting in 1987, two 11mm bores and four 5.5mm bores were arranged randomly in each direction (Fig. 3). In 1988-1990, three of the small nests were 5.5mm and one was 6.0mm in each direction. We did not realize that the 1987-90 random arrangement of nest entrances differed from the 1985-86 pattern of no adjoining entrances until blocks for 1987 had already been prepared. However, we do not believe that this change in nest arrangement affected the bee's behavior.

TABLE 1: Diameter of drill bits used to create trap nests.

| Diameter, mm | Used by<br><u>M. relativa</u> | Used by<br><u>M. inermis</u> |
|--------------|-------------------------------|------------------------------|
| 4.4*         |                               |                              |
| 5.2*         | xx                            |                              |
| 5.5          | xxx                           |                              |
| 6.0          | xxx                           |                              |
| 7.2*         | xx                            | x                            |
| 9.4*         |                               | xx                           |
| 11.0         |                               | xxx                          |

\* Drill bit diameters used before 1987 only.



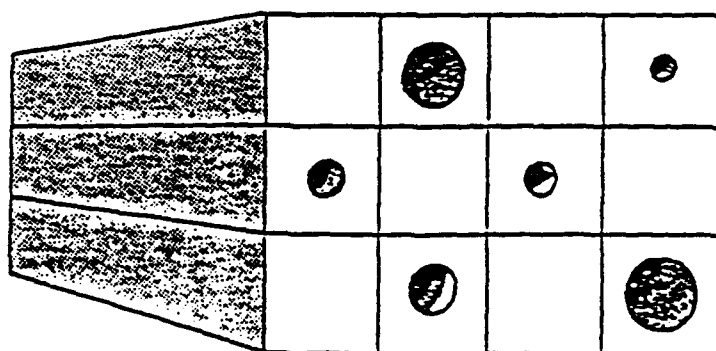


FIGURE 2. Example of arrangement of nests in block, 1983-1986.

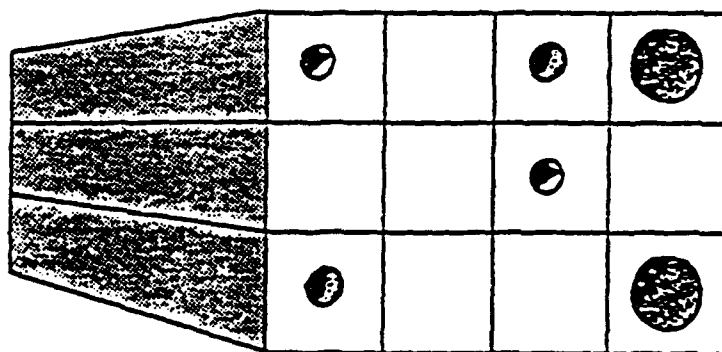


FIGURE 3. Example of arrangement of nests in block, 1987-1991.

"Hutches" consisting of a wooden frame with four shelves and a roof were used to hold the blocks of trap nests (Fig. 4). Four blocks of nests were placed randomly on each shelf, making a total of 192 nests present at any one time. The hutch was open on both sides, so half of the nests opened in each direction. The shelves were roughly 0.1, 0.4, 0.8, and 1.1 meters from the ground.

Four study sites were selected in 1984 for placement of hutches. Two are experimental sites along the ELF antenna: Ford 1 and Ford 2 (F1 and F2), and two are control sites: Camp 5 and County Line (C5 and CL). The study sites are described below. Further information can be found in the 1985 annual report. Three sets of two hutches, making a total of six hutches, were placed at each of the four study sites. In each set of two hutches, one hutch was oriented in a north-south direction so that its nests open to the east or west, and one hutch was oriented in an east-west direction so that its nests open to the north or south. The two hutches in each set were placed close together in edge habitats between open areas where there are abundant flowering plants, and woods where natural nest sites are available.

When a nest was occupied by a megachilid bee, it was given a number that included site (C5, CL, F1, or F2), hutch direction (NS or EW), nest entrance orientation (E, W, N, or S) and shelf height (1-4, top to bottom). This number was written on the side of the nest. Position on the shelf and in the block of nests was not recorded. Starting in 1987, a computer data base was created to help us manage nest numbers and progress of the nesting bees.

Once a nest in progress was identified, the depth of empty tunnel space was recorded daily (pre-1987) or every 2-7 days (1987-90). This information, coupled with nest architecture measurements taken the following spring, allowed us to estimate which cell the bee was constructing on the day the nest was first located. Assuming that the bee takes approximately one day to complete a cell, we estimated the dates on which the nest was begun and finished. Nests were classified as "early season" if they were begun on or before the date on which half of the nests of that species were begun at that site during that year. Nests begun on later dates were classified as "late season" nests. When the nest was completed, it was removed from the block, and replaced with an empty nest of the same bore size.

Each completed nest was stored in a large centrifuge tube with cloth covering the opening. Tubes were placed in wooden overwintering boxes built to fit the hutch shelves. Prior to 1987, completed nests were brought to Channing to overwinter, in order to avoid vandalism and marauding animals. However, starting in 1987, nests were left in overwintering boxes at the site where they were constructed. Starting in 1988, we took care to

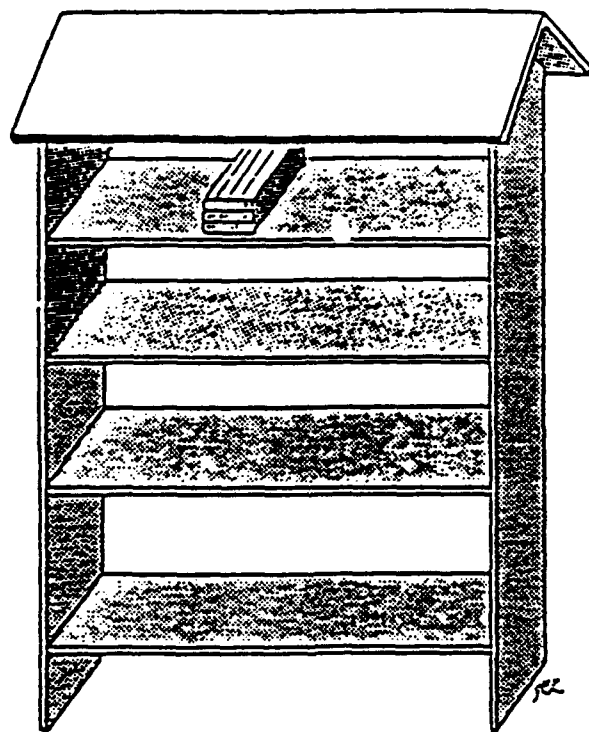


FIGURE 4. Hutch, with one block of nests.

insure that nests were oriented in their original direction. Overwintering boxes were not left on hutch shelves as in the past, but rather were elevated about a foot off of the ground and camouflaged with branches, bark, and leaves in order to avoid vandalism. Fortunately, overwintering boxes have not been vandalized at any of the sites, although hutches have been damaged and have disappeared during the winter.

A manipulative experiment was initiated with nests constructed in 1990, to determine if overwintering mortality differs under the ELF antenna when compared with the control sites. One third of the nests constructed at the F2 treatment site were moved to the C5 control site in mid-September for overwintering. The nests that were moved were chosen to represent hutches and nest begun dates in the same proportions as the nests that remained at the F2 site. The number of F2 nests overwintering at C5 approximately equals the number of C5 nests overwintering at C5. Nests from both sites were placed in overwintering boxes in the same directions as they were constructed, but C5 and F2 nests were mixed and positioned randomly with respect to bottom vs. top, right vs. left side of the overwintering boxes. Mortality of F2 nests overwintered at C5 will be compared with mortality of F2 nests overwintered at F2 and C5 nests overwintered at C5, in fall of 1991. The reciprocal experiment, overwintering C5 nests at F2, could not be conducted because there were insufficient C5 nests. If nest numbers at C5 are sufficiently large in future years we will perform the reciprocal experiment. However, the control sites tend to have lower M. inermis nest numbers than the experimental sites, and 1990 had peak nest numbers at all sites (Table 3) so we do not expect that the opportunity will arise.

### Nest Architecture Measurements

Nests constructed by M. relativa during 1985 were measured after bee emergence, in November and December, 1986. Nests constructed during 1985 by M. inermis were measured after emergence in August, 1987. Most 1986 M. relativa nests were measured before emergence in 1987, so that we would know with certainty the species and sex of the occupant of each cell. The 1986 M. inermis began to emerge in spring 1987 before we began measuring their nests, so most M. inermis nests were measured after bee emergence. The 1987-89 nests were measured sufficiently early in May of 1988, 1989, and 1990 that we were able to complete nest measurements of both species before they emerged in June and July.

After recording nest number and bore diameter, nests were split open lengthwise with a chisel. Total bore depth, non-reproductive spaces (basal space, vestibular spaces, associated caps, nest plugs, and indentation) were

measured with the cells intact. Each cell was then removed and measured from the base of the cell to the position of the outermost leaf in the cell cap (Fig. 5). Cell lengths measured after emergence are likely to be somewhat more variable than cell lengths measured before cell emergence, because emergence damages the cell cap. Thus it is sometimes difficult to determine where the edge of the cell cap starts.

The nest number that is written on each nest includes information on the site where the nest was created, so nest architecture measurements of pre-1988 nests were not blind to site. We doubt that knowledge of the nest site affected our measurements. However, in response to reviewer concern, our measurements of the 1988 and 1989 nests were made blind to site. Before nest measurements were made, students who did not measure nests spent a day crossing out nest numbers and replacing them with a random number independent of site. A data base not available to the nest measurers recorded the original nest number, and the random code number assigned to it. Nests were then measured without knowing at which site they were constructed. After all measurements were complete, the random number was associated with its original nest number, including site.

Since more than one person measures nests, we attempt to divide the nests equally by site and date of nest initiation among all measurers. Thus individual biases in measurement are distributed evenly between sites and dates. In addition, in 1987 thirty-nine M. relativa cells were re-measured to determine within- and between-individual measurement error. Twenty cells were measured three times by each of the four individuals measuring nests. An additional 19 cells could only be measured 1 or 2 times by each measurer, because they were damaged by the multiple measurements. A similar experiment was repeated in 1990, with 3 measurers and 39 M. inermis cells from nests constructed in 1989. Each cell was measured 3 times.

### Emergence Data

Nests created in 1985 were checked daily in the spring of 1986 for bees that had emerged from the nest and were in the tubes. For nests created in subsequent years, after measurement in the Spring, cells from which nothing had yet emerged were placed in individual plastic culture tubes or rearing dishes, and labeled with nest and cell identification numbers. In 1987 and 1988 tubes were kept in the Crystal Falls Laboratory at room temperature (approx. 68°F) until emergence. However, 60 hz EM fields are relatively high in Crystal Falls due to the presence of numerous power lines. In the laboratory, electric lights and wiring in the walls also create relatively high EM fields (ELF Communications System Ecological

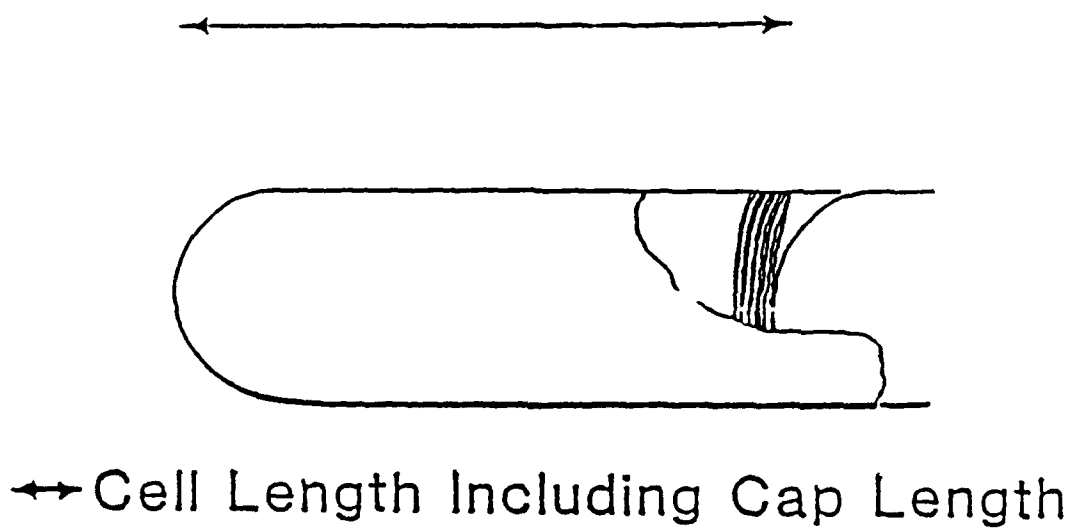


FIGURE 5. A single reproductive cell, indicating how cell lengths are measured.

Monitoring Program: Electromagnetic Field Measurements and Engineering Support - 1990). Therefore, beginning in 1989 unopened nests and rearing tubes were kept at a holding site constructed by the ELF Small Mammal and Bird Project in woods 5 miles south of Crystal Falls. Nests were brought to the Crystal Falls lab only briefly for measurement. There they spent up to 6 hours outside the house where 60 hz fields were lower than in the lab, and no more than 2 hours in the lab for measurements. In addition, starting in 1990, measurements were made in wire mesh Faraday cages constructed by IITRI to minimize exposure of developing bees to electric fields (Fig. 6). Just before and just after measurements, nests and cells were stored in another Faraday cage on the front porch of the Crystal Falls Lab (Fig. 7) for no more than 6 hours.

After nest architecture measurements were complete, cells in tubes were returned to the holding site. Cells were checked daily for emergence. In all years, date of emergence, species, and sex of offspring were recorded. Live weights were also obtained for most bees from 1988 and 1989 nests (see below).

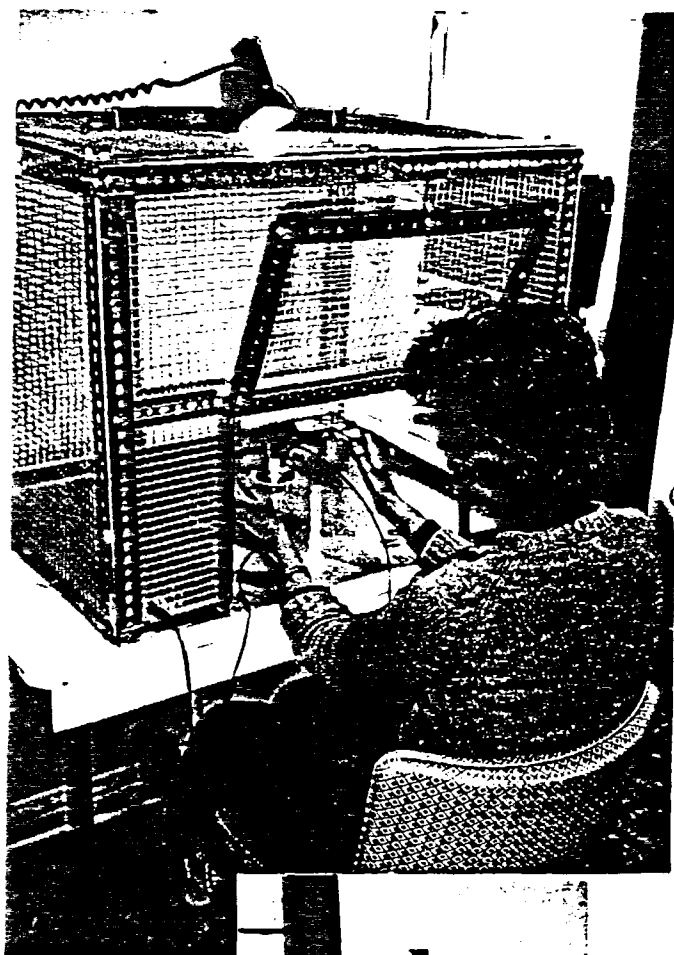
Some bees were saved for dry weight measurements (see below) and identification. Bees were identified by G. Dahlem, V. Scott, and K. Strickler based on Mitchell (1962), and by comparison with reference specimens provided by T. Griswold, ARS Bee Laboratory, Utah State University, Logan Utah.

The remaining adult bees were released at the sites where their nest had been constructed the previous summer. The Faraday cages mentioned above are intended to insure that released bees were not affected by 60 hz electric fields when nest architecture measurements were taken. Effects of 60 hz fields might be mistaken for (or might mask) effects of the ELF antenna's 76 hz fields, and affected bees might alter the genetic makeup of natural populations. Parasites were collected and not released.

Cells that showed no signs of emergence were opened in August (1986-89 nests), or when the nest was measured (1985 nests). Contents were recorded to indicate at what stage mortality had occurred.

**Offspring Weights.** Whenever possible, two or three bees from each 1986 - 1989 M. relativa nest were saved for dry weight measurements and for confirmation of species identification. In 1988-90, M. inermis individuals from 1987-89 nests were similarly saved for dry weight measurements. Dry weight may be a more appropriate measure of parental investment per offspring than is cell length or volume. Dry weight depends directly on the amount of provisions in the cell (see Introduction, p. 2), and provisioning the cell typically takes much more time than constructing the cell. Cell lengths and volumes may vary for a





a



b

FIGURE 6a, b. Wire mesh Faraday cages, used to reduce exposure of nests to 60hz EM fields while nest architecture measurements are made in Crystal Falls.

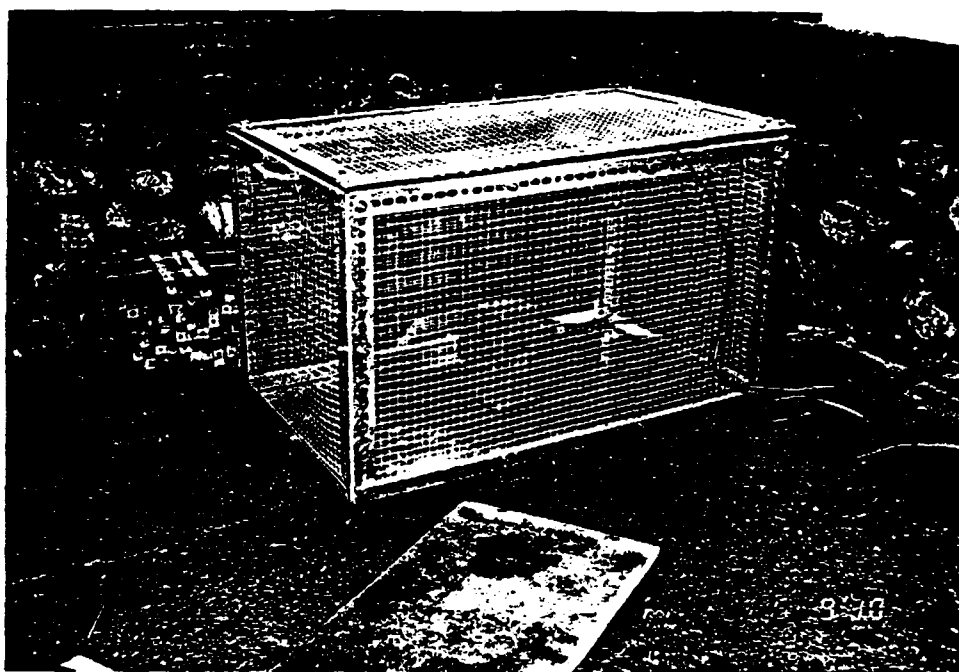


FIGURE 7. Wire mesh Faraday cage on front porch in Crystal Falls, used to store nests and cells just before and after nest measurements are made.

given amount of provisions depending on the number of leaves used in lining and capping the cell. Some authors (eg., Cane, 1987) and one of our reviewers have suggested that measurement of hard body parts is a better indicator of body size than is weight, although the two are correlated (Cane, 1987). Field collected bees, which vary in age and foraging status, may be especially variable in weight. Since bees in this study were collected within hours of emergence without being released, their crops were empty. Thus much of the variability in weights that would be expected from a sample of field collected bees was eliminated. Measurement of hard body parts may still be a better measure of body size, but since we have weight data for our bees from a number of years, since it is relatively easy for us to make weight measurements, even in the field, and since we would have to remeasure many pinned specimens to get measurements of hard body parts, we prefer to continue taking weight measurements at this time.

Weights were obtained by drying bees in a desiccator over  $P_2O_5$  to constant weight. Constant weight was defined as two weights taken 48 hours apart that were within 0.5mg of each other. The lower of these weights was used in analyses.

**Offspring sex, expected sex of a cell, and sex ratio.** Previous analyses indicate that the offspring's sex contributes significantly to variance in cell length and leaves per cell (1989 Annual Report). However, the sex of the offspring was known only for a small proportion of the cells, since many offspring die in the larval and prepupal stages, which can't be sexed. Furthermore, parasites emerge from some cells rather than M. inermis or M. relativa. This year we have decided to create a new variable in our data set that indicates the expected sex of a cell. We can predict the expected sex for many of the cells that did not have a bee emerge. Emergence data for 1987-1989 nests indicates that when a nest contains females, they are almost always in inner cells relative to cells containing males. Only 4 male M. relativa and 7 male M. inermis were ever found in cells behind a female cell, all in 1987. Therefore, cells of unknown sex deeper in the nest than a cell with a female offspring can be assumed to be female. Conversely, cells with unknown sex that follow a male cell can be assumed to be males. Similar deductions have been used in analysis of sex ratio in other studies of trapnesting bees and wasps (Cowan, 1981; Sugiura and Maeta 1989).

The expected sex of a cell is the predicted sex of the cell when sex can be deduced, or the actual sex when sex is known. In statistical analyses where female and male cells are treated separately, expected sex increases the number of cells that can be included in the analysis by 2.6 fold for 1985 M. relativa, by 2.4 fold for 1985 M. inermis, by 1.4-1.6 fold for M. relativa in subsequent years, and by 1.2-1.8 fold for M. inermis in subsequent years.

Expected sex of a cell is a useful variable in analyses of cell length and leaves per cell. However, it is not a good variable to use in estimates of sex ratio of the population. This is because expected sex cannot be deduced in nests that have only a single dead cell, or in nests that have no emergence in the innermost cell and only males in subsequent cells. Since the innermost cell has the highest proportion of female offspring, using expected sex of a cell to estimate sex ratio will bias the sex ratio toward males. Instead, we calculate two estimates of sex ratio. First, the "secondary" or actual sex ratio is the ratio of male to female adult and pupal offspring, which could be sexed with certainty. The "primary" sex ratio is the sex ratio that would have been produced if all cells had yielded an offspring. Primary sex ratios were calculated according to the method of Frolich and Tepedino (1986). Cells of unknown sex were assumed to contain males and females in the same proportions as cells of known or expected sex for a given cell position. The unknown cells at each cell position were multiplied by the proportions of known males and females, and these numbers were summed over all cell positions and added to the cells for which actual or expected sex was known.

### Leaf Counts

The number of elongate leaves that were used to construct a cell was determined for 1985-1989 M. inermis cells and 1986-1989 M. relativa cells that were still in good condition once emergence was complete. Leaves lining M. inermis cells overlapped, but were easy to tease apart and count. Leaves lining M. relativa cells were smaller, and were fastened together so that a microscope was often needed to determine where one leaf ended and the next began. When in doubt, leaf counts were not recorded.

### Data Entry for Nest Architecture, Emergence, and Leaf Count Data

Nest architecture measurements, emergence records, and leaf counts are recorded manually in the spring and summer on data sheets for each nest. In the fall, these data are typed into an R-Base file on a Zenith personal microcomputer, where an initial check for errors is made. The R-Base file is then down-loaded to the VAX 11/730 computer (VAX/VMS operating system) in the Department of Entomology at MSU. Here they are checked further for errors, and loaded into several files in INGRES, a relational data base management program on the VAX. Finally, relevant subsets of the data are transferred from INGRES to SAS data files for statistical analysis.

## Nest Activity

One or more observers have gathered data on behavior of individual bees at the nest every year since 1983. In the 1986 Annual Report, we decided to focus on the collection of round pieces of leaf (LO trips) used in capping a cell. Analysis (1986 Annual Report, p. 20-21) suggested that this was the most consistent of the three main behaviors in nest construction (collection of pollen, collection of elongate leaves for cell lining, and collection of round leaves for cell caps). LO trips probably involve fewer extraneous behaviors such as sunning or taking nectar than do pollen or elongate leaf collecting trips. Thus residuals for the duration of LO trips could be normalized for statistical analysis. Consistency in LO trip durations probably results from the necessity to cap the cell rapidly to avoid parasitism after laying an egg.

Prior to 1987 each observer watched a single bee for several days in succession, until the nest was complete. This protocol generated a great deal of information on the variability in behavior within a bee, but less information on between-bee variability. In 1987 - 1990 field seasons we maximized the number of bees timed per day, rather than timing one bee for long periods of time. Observers became adept at locating a bee that was about to lay her egg, and were able to focus on timing the first few LO trips that the bee made after laying her egg. Generally, we tried to time 5 such trips in succession before searching for another bee that was about to collect LO leaves. Occasionally the bee would complete a cap in fewer than 5 timings. The observer sometimes would time more than 5 LO trips if no other bees were active. Number of trips timed for a bee on a given day ranged between 1 and 18; however, no more than the first eight LO trips are included in our statistical analyses. Occasionally the observer missed recording the time of the first few trips. In 1987 we did not try to record the number of LO trips that the bee made before we began timing. Our 1987 analysis suggested that this "trip rank" number is important (1987 Annual Report), because LO trips tend to increase in duration with each successive trip. Thus, during the 1988-1990 field seasons we attempted to record this number when timings were made. Only LO durations for which this trip rank order was known are used in the current analysis.

During the 1987 - 1990 field seasons, four observers were rotated between sites every 3 to 4 days, so that biases between observers would be distributed evenly between sites and dates. On a given day, two observers visited a control site and two an experimental site.

Prior to 1987, the duration of LO trips was determined by using a watch to record the hour, minute, and second that the bee left the nest and returned to the nest. Since 1987, we have used portable Tandy 102 computers that are programmed as event recorders. When the program

was activated, the observer was prompted for information on the nest number and site, and some weather data (see below). The program automatically numbered the observed activities in sequence. Hitting the space bar recorded the time to the nearest second at which the bee left the nest or returned to the nest. A single letter code was used to indicate what cargo (e.g., LOs), if any, the bee brought back to her nest. These data were down-loaded to a Zenith personal computer at our field headquarters, and later transferred to an INGRES data base file on the VAX computer in the Department of Entomology at MSU. Duration of each trip was calculated in INGRES by subtracting the time when the bee left the nest from the time when the bee returned.

### Weather Data

Because behavior of insects is often affected by such environmental factors as temperature and wind speed, foraging trip durations might be correlated with weather conditions. Some weather data were recorded in the event recorders as each bee was timed during the 1987-1990 field seasons. This included sun conditions (sunny, partly cloudy, cloudy, rain), temperature in the shade on the same shelf as the bee's nest, shading of the block in which the bee's nest was found, relative humidity calculated with a sling psychrometer, average wind speed and speed of wind gusts measured with a Dwyer Portable Wind Meter (hand held). This weather data is downloaded from the Tandy computers to the Zenith, and then to an INGRES file on the VAX computer (as described above for LO durations). However, it has not yet been added to our SAS data set.

Data on long-term trends in temperature and precipitation were also obtained from the ELF Herbaceous Plant Cover and Tree Studies project, based at MTU. Dr. Hal Liechty of the MTU project kindly provided us with an asci file of daily summaries of average, 3 hr. minimum, and 3 hr. maximum air temperatures, and total daily precipitation. Ambient monitoring of air temperature and precipitation (among other variables not of interest to us) takes place at MTU's Red Pine Plantation sites: a treatment site under the ELF antenna, 10 miles North of our F1 site; and a control site 9 miles south of Crystal Falls. Despite the distance between the MTU sites and the sites that we are using in the Native Bee ELF project, major climatic trends and differences between years in temperature and precipitation are representative for the region. Climatic trends correlate with floral resources and thus with bee population size, cells per nest, offspring weight, and % mortality. For further information on the MTU ambient monitoring system, see Appendix B of the 1985 Herbaceous Plant Growth and Tree Studies Project Annual Report.

## Description of sites

Three sites are located on Copper County State Forest Property in Dickinson Co. in the Upper Peninsula of Michigan. A fourth site (C5) is located in Iron Co. on property leased by the Michigan Department of Natural Resources to Champion Paper Company. Permission to use these sites is gratefully acknowledged.

The C5 site is located 6.7 km south of Route 69 and about 0.8 km west of Camp 5 road in Iron County, Michigan (Township 42N, Range 31W, Section 14). The area has recently been logged, and nearby forests continue to be logged within a km. of our hutches. An abandoned railroad bed runs N-S through the site. Camp 5 creek runs through the site, creating a cut-over swamp and flood plain. Two hutches are located at the south edge of this flood plain, and two hutches are located in an open depression next to the abandoned railroad bed. Until mid July 1990 the last two hutches were at the north edge of the flood plain, north of C5 creek. This site was not close to Cirsium palustre populations, and attracted few M. inermis.

In spring, 1990 we discovered that a beaver had made a dam across C5 creek, making access to the north hutches impossible by crossing the creek next to the railroad right-of-way. For several months we walked around the edge of the flood plain to reach the north hutches. However, as the water behind the dam increased, the flood plain turned into a shallow lake. When the water came within 10 feet of the north hutches, we decided to move them to the south side of C5 creek. On July 25 the hutches were moved to an elevated site about 20 feet west of the railroad right-of-way, near a large patch of Cirsium palustre. The bee population that uses nests at these hutches should be the same as in the original location. However, being closer to flower populations, more bees may nest at the new location.

Nearby woods consist primarily of Populus tremuloides, with occasional Larix decidua, Picea glauca, Pinus resinosa, and Prunus serotina. Shrubs in the vicinity include Alnus rugosa, Vaccinium sp., Salix sp., Spirea alba, and Rubus allegheniensis. Herbaceous plants include Cirsium palustre, Fragaria virginiana, Hieracium spp., Trifolium spp., and Solidago spp.

The CL site is located about 1.7 km north of Route 69 on the east side of County Line Road, in Dickinson Co., (Township 43N, Range 30W, Section 19). Logging continues within a km or so of the hutches. This site has very sandy soil and is the driest of our sites. Hutches are located at the edge of clearings in Populus tremuloides woods, with occasional Acer saccharum, Betula papyrifera, Abies balsamea, and Pinus resinosa. Two hutches are adjacent to a patch of trees north of a logging road through the

sandy clearing. Two are east, and two west of a marshy, low lying area south of the logging road. Hieracium aurantiacum carpets the ground at this site in June, if rain has been sufficient. Bracken fern is common near the east hutches which are in a shadier location than the others. Other flowering plants that are common in the area include Cornus canadensis, Campanula rotundifolia, Fragaria virginiana, Rubus spp., Solidago spp., Vaccinium spp., and Prunus pensylvanica. Small patches of Cirsium palustre grow in the marshy area south of the logging road. Epilobium angustifolium was abundant at this site in 1983, but decreased rapidly thereafter. Only a couple of stems were present in 1987, and none in subsequent years.

Low numbers of M. inermis nests at the CL site, especially in 1986, prompted us to transplant about 90 Cirsium spp. plants (a common pollen source at other sites) to the CL site in April, 1987 and 50 plants in June 1989 to try to increase the numbers of M. inermis that nested there.

The F1 site is located south of Turner Road, and north of the Ford river, 20 km east of Channing. (Township 43N, Range 29W, Section 14). The hutches are located at the edge of a flood plain, bordered on the north by a Red Pine plantation, and the south by vegetation along the river consisting of Populus balsamifera, Populus tremuloides, Fraxinus nigra, and Alnus rugosa. A corridor has been cut through the pine plantation to allow for the construction of the ELF antenna, which runs NE-SW through the site. Two hutches are east of the antenna, at the north edge of the flood plain. Two are a similar distance west of the antenna. Two are in a shady clearing further west of the antenna at the northwest edge of the flood plain. Flowering plants near the hutches include several species of Cirsium, especially C. palustre and C. arvense, Urtica dioica, Solidago spp., Hieracium aurantiacum, Hypericum perforatum, Aster spp., Rubus spp., Humulus lupulus, Linaria vulgaris, and Vaccinium spp.

The F2 site is located about 0.8 km south of the Ford River and the F1 site, along the clear cut for the ELF antenna. The soil is sandy. Three of the hutches are located on top of a hill at the edge of the clear cut west of the antenna, and along an old logging/hunting trail running west from the antenna. Three hutches are located in a valley east of the antenna. Nearby woods consist of Populus tremuloides, with occasional Picea glauca, and Pinus resinosa. Centaurea maculosa has increased since 1983 until it is now the most abundant flowering plant on the hill. Also abundant are Cirsium palustre, Fragaria virginiana, Hieracium aurantiacum, Coronilla varia, Prunus virginiana, Rubus idaeus, Solidago spp., and Trifolium spp.



## Floral Resource Levels

We noted in the 1989 Annual report that some aspects of the biology of our study populations of M. relativa and M. inermis, such as number of cells per nest and population sizes, seem to be related to the availability of floral resources. Floral resources, in turn are affected by climatic factors such as temperature and precipitation. However, no direct measures of floral resources were made between 1987 -1989. In 1990, monitoring of inflorescences in bloom for three different species in the Compositae was undertaken at all four of our sites. These species are thought to be important pollen sources for the two Megachile species under study, especially for M. inermis. They were Hieracium aurantiacum, Cirsium palustre, and Centaurea maculosa. Further information on our flower monitoring methods and results will be forthcoming in future reports.

## ELF Antenna Operations

In interpreting results of this project it is important to know the pattern of antennal operations in past years (Table 2). The Michigan Transmission Facility (MTF) began testing at 10% power (15 amperes) periodically from March - October, 1986 and with increasing regularity from May - November, 1987 and January - July, 1988. Because analyses for 1986 and 1987 data did not show any effect of experimental and control areas on nest architecture and activity, we regard these years as non-treatment years. Starting July 6, 1988 and lasting until May, 1989, testing continued at 50% power (75 amperes). In our analyses we have variously included 1988 as a treatment year, or as a non-treatment year, in an attempt to see if 50% ELF fields might be having an effect.

In June 1989, the ELF antenna began testing periodically on full power (150 amperes). Continuous full power operation did not begin until October, 1990. In this year's analyses, both 1989 and 1990 are considered full power summers for nest activity data, and 1989 is considered a full power year for nest architecture data, although exposure was greater in 1990 than in 1989. 1989 is a full power year for overwintering mortality data, since continuous full power operations began by the winter of 1989-90.

For detailed information on EM measurements at the sites involved in this study, see the technical reports, ELF Communications System Ecological Monitoring Program: Electromagnetic Field Measurements and Engineering Support prepared by IITRI for each year of the program.

## Statistical Methods

The General Linear Models (GLM) procedure on SAS (Version 5) was used to analyze sources of variability in cell lengths (both species), leaves per cell (*M. inermis*) and LO trip durations (*M. inermis*). In past annual reports, each cell or LO duration was treated as an independent measurement in the models. As pointed out by one reviewer, this analysis is inappropriate if cell lengths or leaves per cell within a nest, and/or LO durations within a cell capping bout, are autocorrelated. To account for this autocorrelation, we calculate a mean cell length or leaf number for each nest, or a mean LO duration for the first three LOs in a cell capping bout. GLM analysis was accomplished on these means. In this model, the error variance consists largely of between nest variability.

In GLM analyses, means of LO duration per cell capping bout were weighted by the number of trip ranks (1-3) that were used to calculate the mean. However, means of cell lengths and leaves per cell were not weighted by number of cells per nest.

Incomplete cells (without a cell cap) were not included in calculations of mean cell length for a nest. Not all cells could be measured in some nests, because some of the cells were destroyed by emerging bees. This may have biased the mean cell length of the nest, if most of the unmeasurable cells were inner cells or outer cells, or consisted of primarily one sex. However, different nests with unmeasurable cells are expected to have different biases, and thus the biases should cancel each other. Thus no attempt was made to adjust for such biases.

Taking a mean for each capping bout does not account for systematic changes in LO duration with trip rank in a capping bout. A second analysis of LO durations did not involve means, but included each LO trip between trip rank 1-8. Nest number was a class variable in the model, and trip rank was a covariate. A significant nest number main effect indicates significant differences between LO durations for each nest. (Nest number is the same as a cell capping bout). Each year was analyzed separately in these analyses, because of the large amount of disk space and computer time required to handle the large number of nests in the analysis.

In all analyses, experimental vs. control areas (Exp), sites nested in experimental and control areas (Site[Exp]), observers or measurers nested in year, complete vs. incomplete nests, and early vs. late season nests were treated as fixed class variables. Number of cells per nest, nest diameter, and bore depth were covariates in the analysis of cell lengths and leaves per cell. Rank order of the trip (trip rank), and date of the trip were covariates in the analysis of LO trip durations. Time was tested as a second order covariate in this analysis. Significance would indicate that LO

Year and Season of Nest Construction or Overwintering:

| ELF EM Field | 1985                    |   |   | 1986 |   |     | 1987 |     |     | 1988 |     |     | 1989     |      |        | 1990                |      |      | 1991 |      |      | 1992 |      |      | 1993 |      |      |
|--------------|-------------------------|---|---|------|---|-----|------|-----|-----|------|-----|-----|----------|------|--------|---------------------|------|------|------|------|------|------|------|------|------|------|------|
|              | Su                      | W | 0 | Su   | W | 0   | Su   | W   | 0   | Su   | W   | 50% | Su       | W    | 100%** | Su                  | W    | 100% | Su   | W    | 100% | Su   | W    | 100% | Su   | W    | 100% |
|              | 0                       | 0 | 0 | 10%  | 0 | 10% | 10%  | 10% | 10% | 50%  | 50% | 50% | 100%**   | 100% | 100%   | 100%                | 100% | 100% | 100% | 100% | 100% | 100% | 100% | 100% | 100% | 100% | 100% |
|              | Antenna Pre-operational |   |   |      |   |     |      |     |     |      |     |     | Testing* |      |        | Antenna Operational |      |      |      |      |      |      |      |      |      |      |      |

Year of Data Analysis:

|                                |      |      |      |      |      |      |        |        |
|--------------------------------|------|------|------|------|------|------|--------|--------|
| Activity Data                  | ---  | ---  | 1987 | 1988 | 1989 | 1990 | 1991   | ---    |
| Architecture Data              | 1987 | 1987 | 1988 | 1989 | 1990 | 1991 | 1992 → | ---    |
| Overwintering (Emergence Data) | 1987 | 1987 | 1988 | 1989 | 1990 | 1991 | 1992   | 1993 → |

\* Treated variously as pre-operational or operational.

\*\*Not continuous operation in SU 1989.

TABLE 2. Time Line of ELF antenna operations, nest construction and overwintering, and data analysis.

durations are faster (or slower) during the middle of the day, as might be the case if LO durations are correlated with temperature. Type IV mean squares were calculated in all GLM analyses. This model is invariant to the ordering of effects in the model.

The mean square (ms) of Site[Exp] was used as the error term for testing the significance of Exp, and interactions between Exp and other variables in the models. This insures that differences between experimental and control areas are greater than any differences between the sites that comprise the areas. The ms of measurer[yr] was the error term for testing year, and interactions between year and other variables in the model. This insures that differences between year are greater than the differences between measurers who took data in any given year. For M. inermis, the interaction between year and bore depth was included in most models because depths of the largest diameter bores varied between years.

The ms of Site[Exp] was used as the error term to test for significance of the interaction between Year and Exp. If significant, this interaction term indicates that one area has shown a greater change between years than the other. Ideally this interaction term will not be significant before the antenna is operational. If the Exp main effect is significant but not the Exp\*Year interaction, then we know that there are intrinsic differences between experimental and control areas that have nothing to do with the antenna. If the year main effect is significant but not the Exp\*Year interaction, then we know that there are differences between years that have affected both experimental and control areas equally, as would be the case for climatic changes between years. If the Exp\*Year interaction is not significant before the antenna is operational, but it becomes significant after the antenna is operational, the antenna is a likely cause of the difference. If the interaction term is significant before the antenna is operational, then the problem of detecting differences between experimental and control areas will be much more complex.

In cases in which sample sizes (ie, number of nests) were small in some years at some sites, the data for pre-operational years were pooled and compared with the pooled data for operational years. Since the antenna was tested at 50% power in 1988, two different pooled analyses were tried. In the first, 1988 data were pooled with operational years (1989), while in the second 1988 data were pooled with pre-operational years (1985-1987).

A Shapiro-Wilk statistic for  $N < 51$  and a Kolmogorov D statistic for  $N \geq 51$  in the Univariate procedure of SAS were used to test for normality of residuals in models of LO trip durations, cell lengths, cell volumes and leaf counts. The data are tested against a normal distribution with mean and variance equal to the sample mean and variance. The significance level used in these tests was 0.05. Ln or lnln transformations of the data

were sometimes required to meet the assumption of normality of residuals. When used, such transformations are discussed in the Results section.

Minimum detectible differences between experimental and control areas (Exp) were estimated with a modification of Cochran and Cox's (1975) formula (Zar, 1984 p.135, 137, 260). Sample size used in this formula was the harmonic mean of the treatment and control area sample sizes (Zar 1984, p. 137) based on numbers actually collected each year for the control and experimental sites. The value of population variance  $s^2$ , used in calculating minimum detectable differences was the Site[Exp] mean square because this mean square value is used as the error term for testing Exp and Exp\*Year, and thus is the denominator in the F test of the GLM analysis (Zar, 1984 p.260). Values of  $\alpha$  and the power of the test ( $1-\beta$ ) were 0.05 and 0.9 unless otherwise stated. We would prefer to test for the minimum detectible difference for the Exp\*Year interaction, but we do not know how such a test would be made.

A two-way classification model II ANOVA was used to analyze within- and between- measurer components of cell length variability (Sokal and Rohlf, 1969, p.315). In this analysis, measurer and cell number were random effects. The error mean squares gives within-measurer variability.

The Categorical Data Modeling (CATMOD) procedure on SAS was used to compare distributions of cells per nest from experimental and control areas. This statistical program fits linear models to functions of response frequencies for discrete data; ie., it is an extension of the GLM procedure for continuous data that was used in the analyses of cell lengths and volumes. The program uses a Wald statistic (which approximates a chi-square distribution for large sample sizes) to test hypotheses about linear combinations of the parameters in the model. As with the GLM tests previously described, we tested for significance of experimental vs. control areas (Exp), Sites nested in Exp areas (Site [Exp]), Year, the interaction between Exp and Year (Exp\*Year), and early vs late season. The level of significance of all tests was 0.05.

Proportion of nests oriented in a N-S vs. E-W direction was tested against the prediction of equal proportions in each direction. When at least 10 nests were constructed at each matched set of hutches for a given year and site, a heterogeneity Chi-Square Goodness of Fit test was used (Zar 1984, p.49). When a bias was discerned in the nest directions accepted by bees at a hutch set or site (ie., the null hypothesis in the Goodness of Fit test was rejected), then a log-likelihood ratio heterogeneity contingency table analysis (Zar 1984, p. 67-68) was used to determine if the bias was the

same for all years at a given hutch set, and for all hutch sets at a given site.

Proportion of mortality in the overwintering prepupal stage was tested with the ANOVA procedure in SAS in a randomized block design. Proportions were transformed using a Freeman and Tukey arcsine transformation (Zar 1984, p. 240):

$$pft = 1/2 [\arcsine \sqrt{X/(n+1)} + \arcsine \sqrt{(X+1)/(n+1)}].$$

Two additional transformations were tried in ANOVAs. These included Ascomb's arcsine transformation (Zar 1984, p. 240), and the Probit of Rao's transformation (Rao 1965). Since all three transformations usually gave very similar results, we report here only the Freeman and Tukey arcsine transformation, which is preferable for small proportions. Analysis using this transformation usually had the greatest  $r^2$ .

Resulting values were analyzed in an ANOVA to determine whether Site[Exp], Year, Exp, and Exp\*Year, contribute significantly to variability in proportions. The ms of Site[Exp] was used as the error term for testing the significance of Exp, and interactions between Exp and other variables in the ANOVA. Calculation of proportion of prepupal mortality was complex, and will be explained in the results section.

## IV NEST ARCHITECTURE RESULTS

### Climate, Floral Resources, and Bee Abundance

Table 3 and Figs. 8 and 9 summarize the number of nests of the two species for which we have data on cell lengths, and an estimate of the number of complete nests created in 1990. Some 1985 M. inermis nests were not included in our measurements because Dr. Fischer, who initiated this research project, used them in experiments on diapause. Nest numbers in Table 3 for 1985-1989 differ somewhat from numbers reported in previous years because nests were not counted if they had only a single incomplete cell, or if all cells were unmeasurable. The 1983 nest architecture data have not yet been incorporated into our analysis, although the data have now been typed into the Rbase program on our Zenith computer, and will be transferred to the VAX computer and incorporated in next year's analysis. Nests constructed in 1990 will be measured in the spring of 1991, so number of nests are estimates for this year.

Between 1985 and 1989 M. relativa has produced similar numbers of nests at all sites (36-164), with no consistent differences between control and treatment sites (Fig. 8). Our projections of 1990 nests indicate a reduction in M. relativa populations at the C5, CL and F1 sites and an increase at the F2 site, but these estimates may be in error. In contrast, M. inermis produces a consistently lower number of nests at the control sites than at the experimental sites. Furthermore, M. inermis nest numbers at all sites were lower in 1986 and 1988 (except for F2 in 1988) than in other years. We believe that this reduction in the bee population was caused by a reduction in floral resources due to low rainfall, especially early in the season. Fig. 10 plots cumulative precipitation for 1986 - 1989. The first nests of M. relativa and M. inermis are indicated on the plots, along with first bloom (when known) of two important pollen plants for the bees: Hieracium aurantiacum, and Cirsium palustre. In 1986 and 1988, bee nesting and plant flowering began when less than 4 inches of rain had accumulated, whereas in 1987 and 1989 the same events began after 4-5 inches of rain had accumulated. Although no quantitative measures of numbers of flowers in bloom were made, we did note that H. aurantiacum, which normally creates a carpet of orange flowers during peak bloom, produced very few capitula (inflorescences) in both 1986 and 1988. Thus, newly emerged bees beginning their first nests may have been faced with a dearth of floral resources. M. inermis numbers were not affected as strongly at the F2 site in 1988 because of a substantial population of Centaurea maculosa that bloomed in late July, in spite of the drought and hot temperatures. This plant was not as abundant at the F2 site in 1986. It is absent from the CL and F1 site, and was only found in low numbers at the C5 site in 1988.

TABLE 3: Number of nests of M. relativa and M. inermis at each site for which we have data on complete cell lengths.

| Site Year           | Control Sites |             | Test Sites     |                |
|---------------------|---------------|-------------|----------------|----------------|
|                     | Camp 5        | County Line | Ford 1 (North) | Ford 2 (South) |
| <u>M. relativa</u>  |               |             |                |                |
| 1985                | 51<br>(5)     | 78<br>(6)   | 84<br>(5)      | 92<br>(6)      |
| 1986                | 49<br>(6)     | 51<br>(5)   | 42<br>(5)      | 80<br>(5)      |
| 1987                | 78<br>(5)     | 47<br>(5)   | 76<br>(4)      | 47<br>(5)      |
| 1988                | 85<br>(6)     | 59<br>(5)   | 83<br>(5)      | 51<br>(6)      |
| 1989                | 75<br>(6)     | 60<br>(5)   | 38<br>(3)      | 73<br>(6)      |
| 1990*               | 43<br>(5)     | 52<br>(5)   | 36<br>(4)      | 164<br>(6)     |
| <u>M. inermis</u>   |               |             |                |                |
| 1985 nests measured | 23<br>(3)     | 17<br>(2)   | 160<br>(6)     | 88<br>(6)      |
| nests constructed** | 26            | 18          | 212            | 121            |
| 1986                | 15<br>(1)     | 2<br>(0)    | 40<br>(3)      | 65<br>(4)      |
| 1987                | 56<br>(3)     | 25<br>(3)   | 122<br>(5)     | 108<br>(6)     |
| 1988                | 30<br>(4)     | 7<br>(0)    | 54<br>(2)      | 127<br>(5)     |
| 1989                | 106<br>(6)    | 23<br>(3)   | 172<br>(6)     | 262<br>(6)     |
| 1990*               | 130<br>(6)    | 48<br>(3)   | 184<br>(6)     | 297<br>(6)     |

\* Approximate numbers; Complete nests only; not yet measured

\*\* Some 1985 nests were not measured because they were used in a study of diapause. I do not have these nests, nor do I have the data from the diapause study.



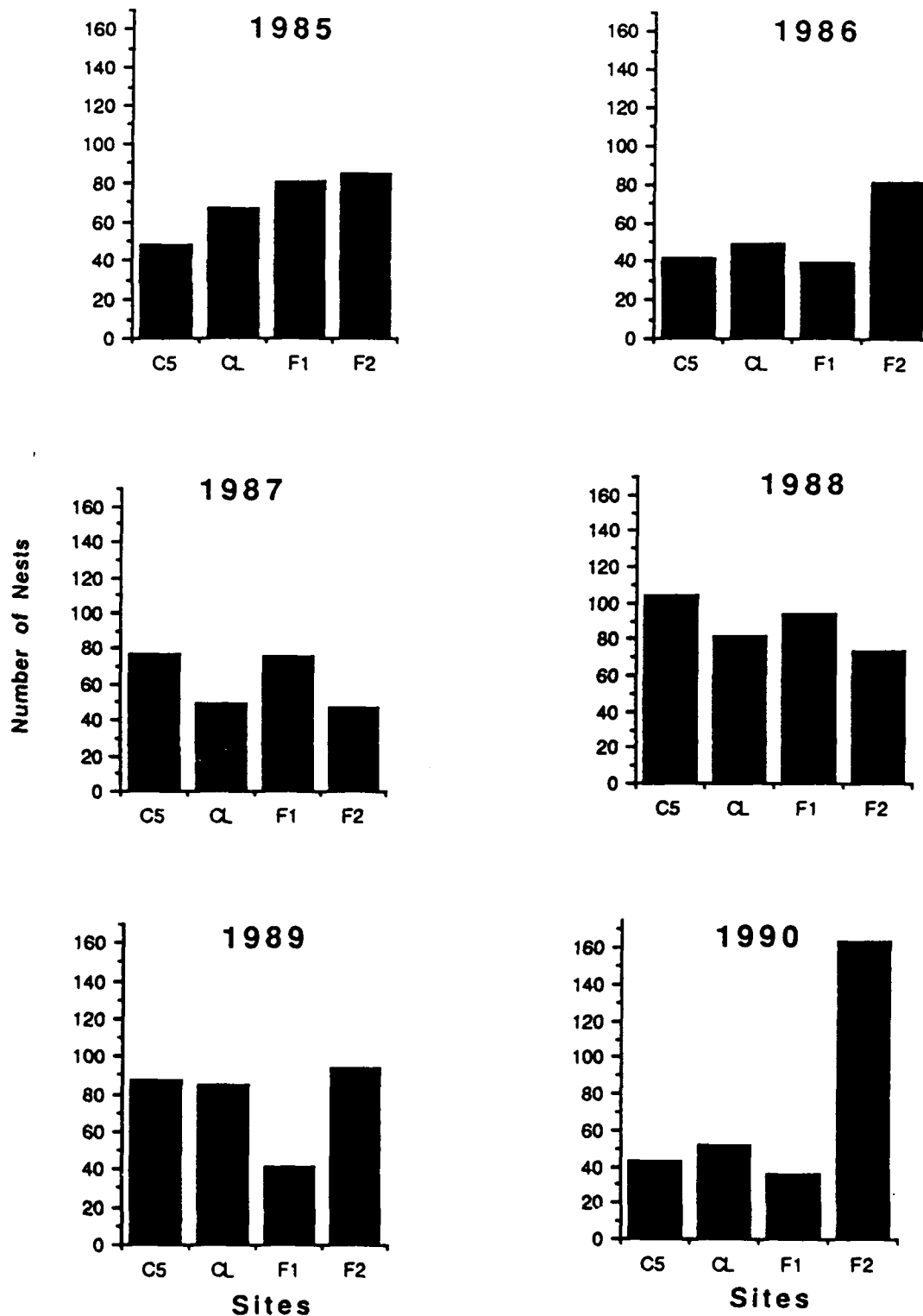


FIGURE 8. Number of nests of Megachile relativa constructed at four sites, 1985-1990.

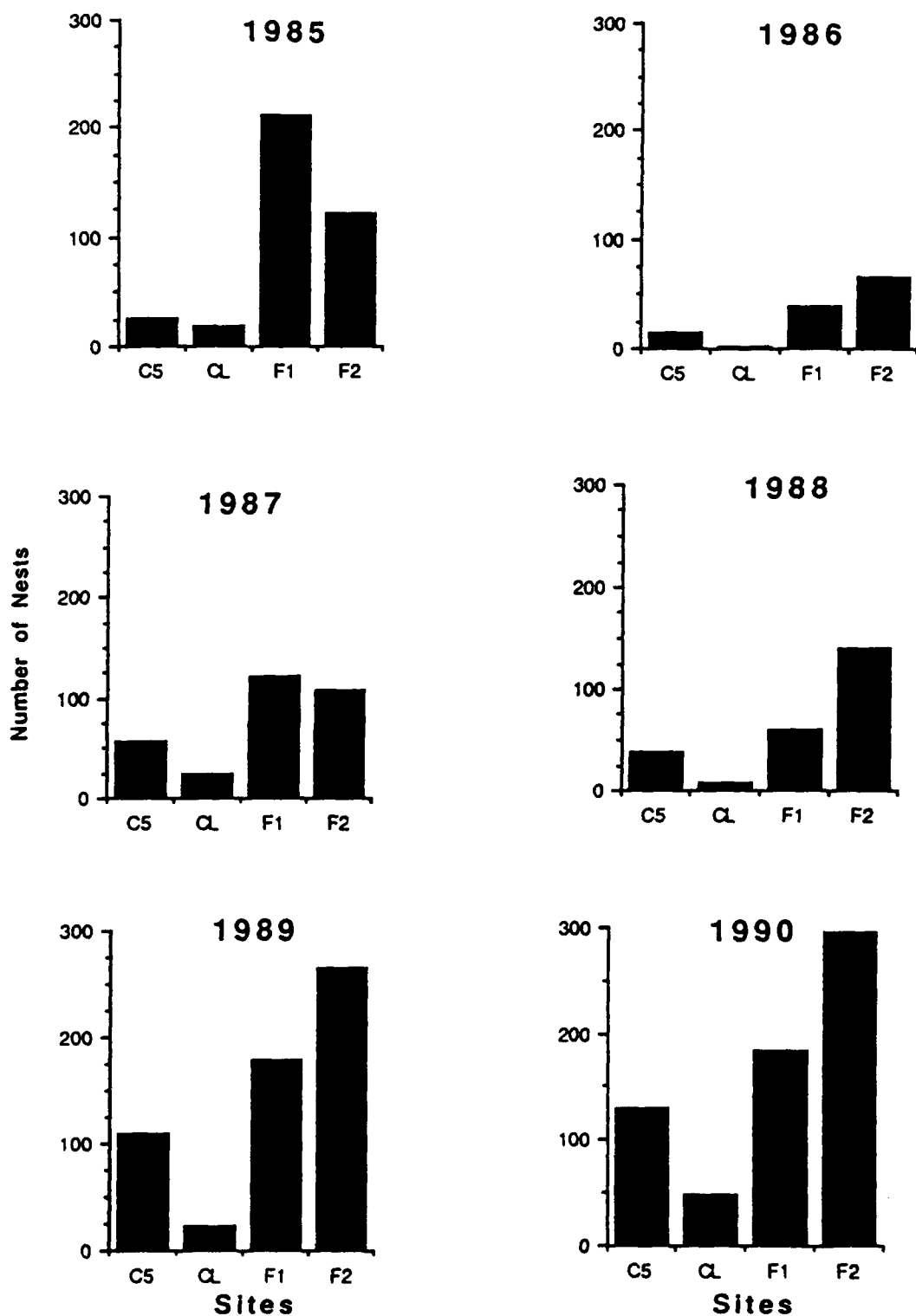


FIGURE 9. Number of nests of *Megachile inermis* constructed at four sites, 1985-1990.

# CUMULATIVE PRECIPITATION

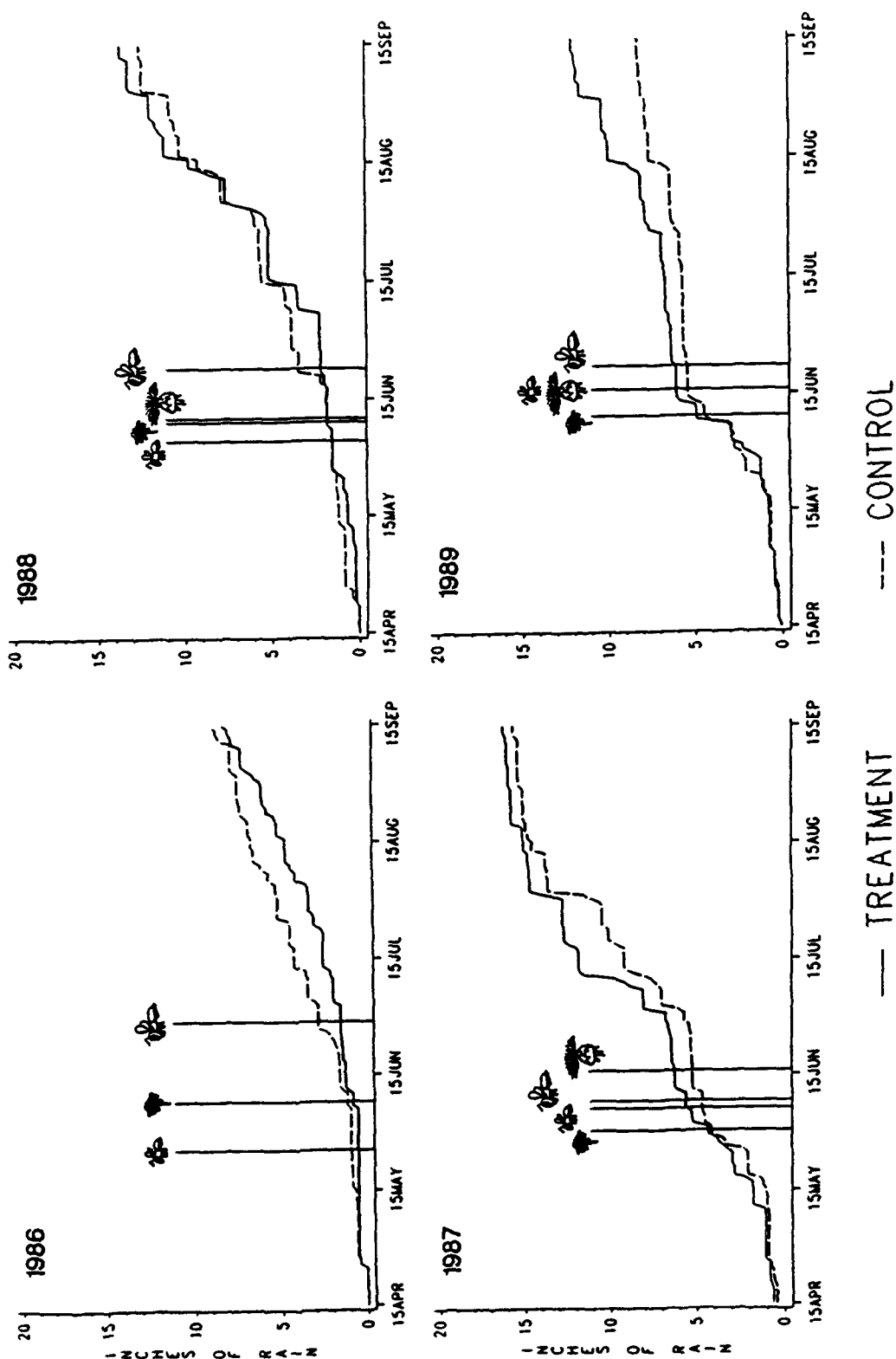


FIGURE 10. Cumulative precipitation at MTU pine plantations.

Cumulative numbers of nests constructed over the season at the four sites are presented by year in Fig. 11. Final nest numbers are underestimates for M. inermis in 1985, as explained above. There are differences between sites and years in dates of first and last nest construction, and in rates of nest construction through the season. M. inermis generally started nesting later than M. relativa. Both species began nesting earlier in June in 1987 than other years. M. relativa began nesting later in 1985 and 1989 than in other years. Accumulation of nests was slower at most sites during the drought years of 1986 and 1988 for M. inermis. This was not true for M. relativa.

The midpoint of the season varied between years, sites and species. Vertical lines on Fig. 11 indicate the date on which 50% of the nests had been started for each species, site and year. This date was the last date on which nests were classified as early season nests. Early season ended later for M. inermis than for M. relativa in 1985, 1986, and 1989.

We are not entirely satisfied with this measure of early vs late season. Next year we may redefine early and late season as the date on which 50% of the nests were begun for all sites pooled in a given year, rather than separately for each site and year. This would more accurately reflect the fact that bees tend to show signs of aging late in the season (Strickler, 1982; Tepedino and Torchio, 1982). In our current calculations, late season begins in June at some sites (eg., CL, 1987, Fig. 11). This probably reflects the fact that bees left the area after H. aurantiacum finished blooming. The June early season ending date does not reflect aging of the bees making the nests.

Of 90 Cirsium transplanted to the CL site in 1987 in an attempt to increase the M. inermis population, about one fourth survived and bloomed. No new transplants were made in 1988 because they would not have survived the spring drought. An additional 50 plants were transplanted in June, 1989 into the marshy area of CL. We do not know how many successfully bloomed, because numerous endemic thistle bloomed in the marsh in 1989. These transplants probably did not provide enough additional resource to affect bee populations.

In 1987, bee nesting seemed to be synchronized with peak H. aurantiacum (hawkweed) bloom. In 1988, very little hawkweed bloomed, because of drought. Flower abundances recovered in 1989 and 1990, but in these years nesting began after peak hawkweed bloom. Once the bees began foraging, their nesting activity reached typical levels at most sites, even though peak hawkweed bloom had passed. Flower abundances were the highest yet observed on this project in 1990, even at the CL site, and this is reflected in large M. inermis populations.

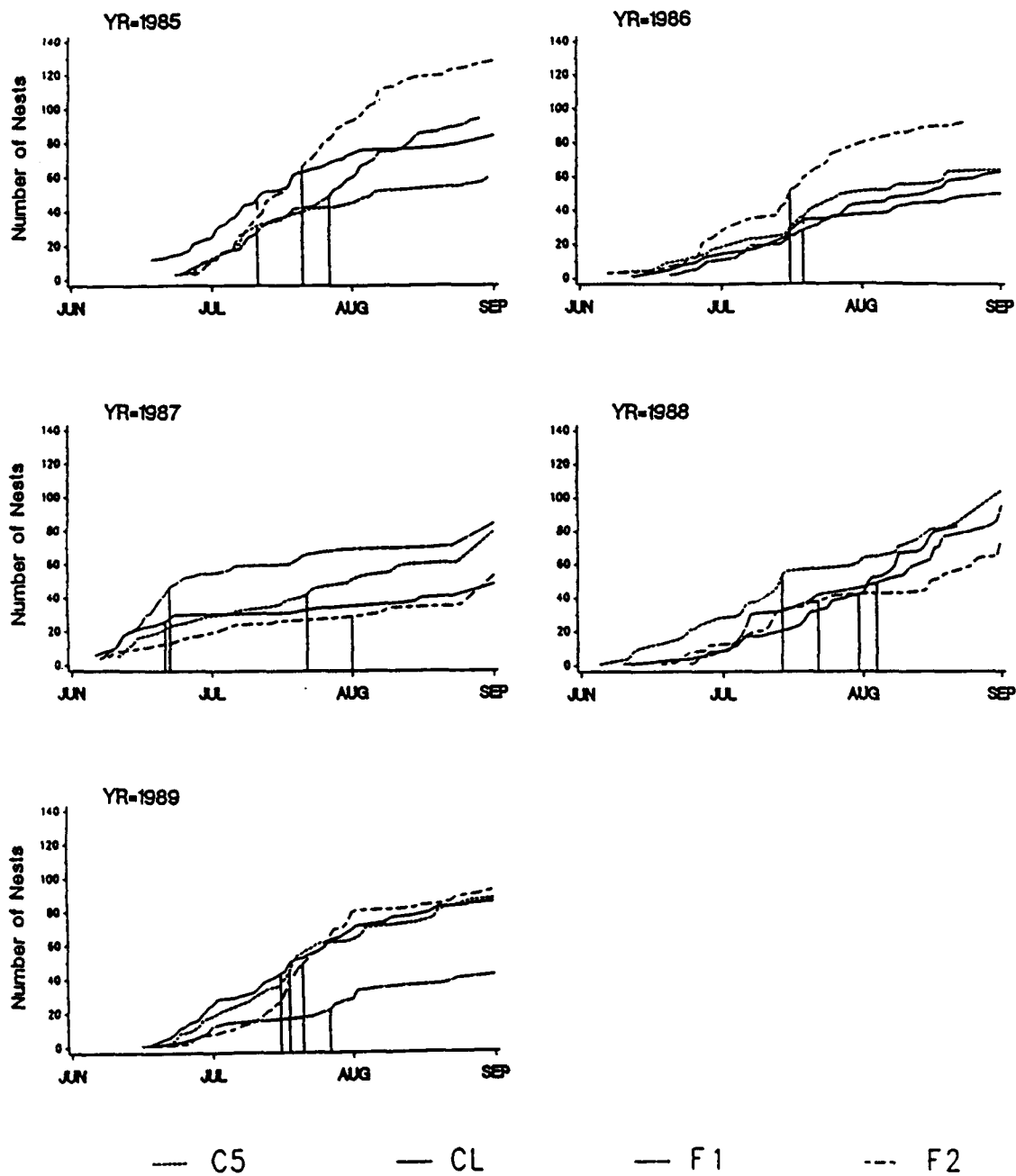


FIGURE 11a. Cumulative number of nests of M. relativa at each site, 1985-1989.

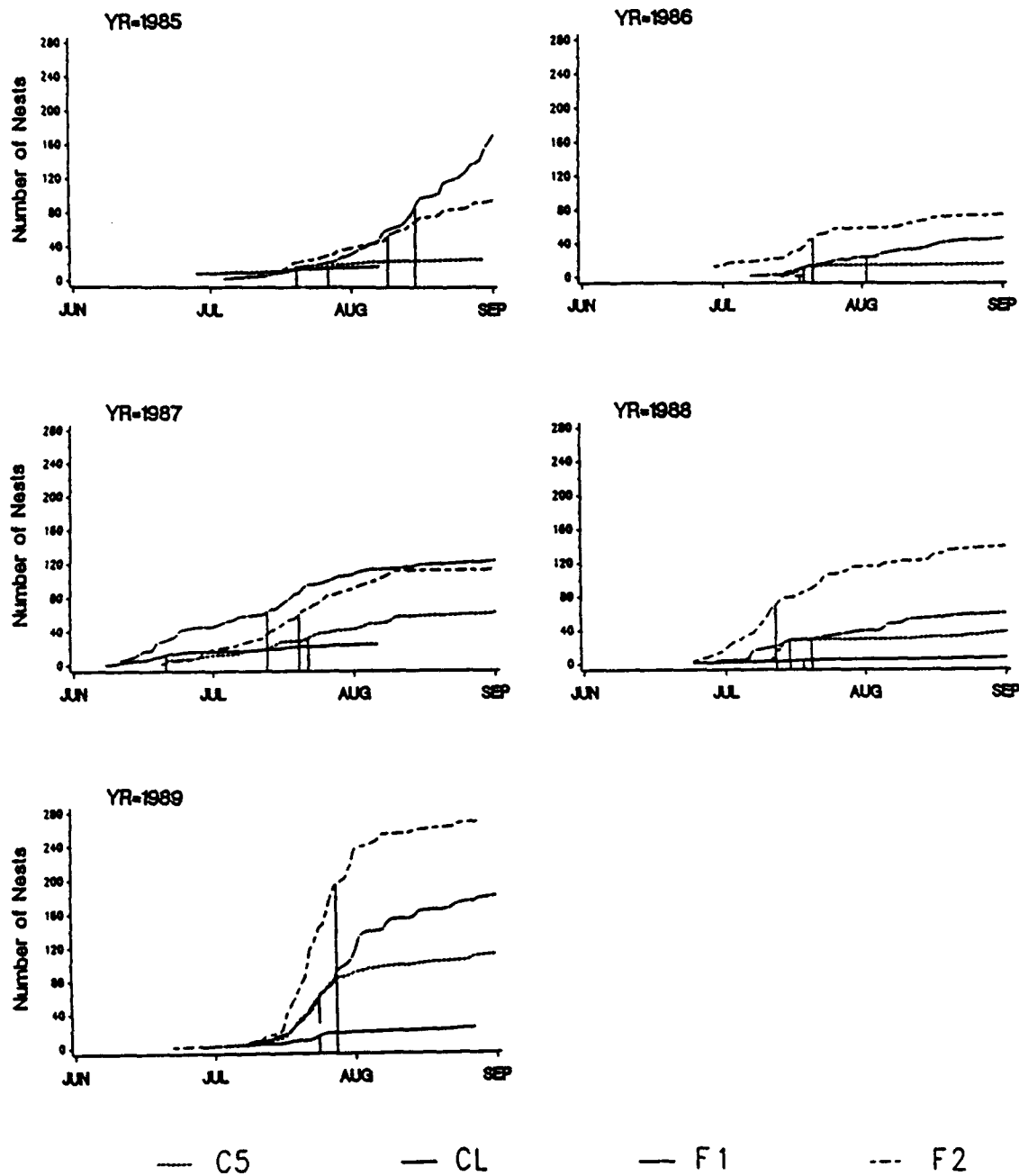


FIGURE 11b. Cumulative number of nests of M. inermis at each site, 1985-1989.

**Hypothesis 1:** The average length of cells for each offspring, and/or the average number of cells produced per nest is unchanged by exposure to ELF electromagnetic fields.

### M. relativa

Mean cell length was calculated for each nest, and used in GLM analysis. If ELF EM fields have an effect on cell lengths we would expect to see mean cell lengths changing for the treatment sites but not for the control sites in 1989, and possibly in 1988. This does not seem to be the case. There were no consistent trends of differences between experimental and control sites, either in pre-operational years, or under full power in 1989 (Fig. 12). Indeed, the means for control and experimental areas overlapped considerably before and after the antenna became operational. Dashed horizontal lines bracketing the means for each year in Fig. 12 indicate upper and lower limits to the minimum detectable differences between control and experimental means for that year. Difference between actual means was always less. GLM analysis (Table 4) confirms that neither Exp nor Exp\*Year contribute significantly to variation in mean cell length. Therefore, there does not yet appear to be any influence of ELF EM fields on cell length for this species. However, it is possible that differences in mean cell length will be detected in future years when bees are exposed to continuous full power EM fields.

Cells from the CL site tended to be slightly but significantly larger than cells from other sites, and cells were significantly smaller in 1985. The significant year effect is probably a consequence of the fact that bees emerged before cells were measured in 1985. Cell bases are convex before the bee emerges, (Fig. 5), but once the bee chews through the cell in front of it, the cell base is truncated, and the cell measurement is slightly reduced.

Overall, mean cell length per nest was 11.1mm for M. relativa. The model accounted for only 19% of the variance in mean cell lengths (see  $r^2$  in Table 4). Between nest variability (error ms) is large. Cell lengths decreased slightly as diameter increased. In addition, cell length decreased as the number of cells in a nest increased. This may reflect in part a decrease in cell length as cells get closer to the nest entrance. Nests with few cells have large, inner cells, so mean cell length is large. Nests with many cells include small cells near the nest entrance, so mean cell length will be lower than for nests with few cells. Cells lengths in early season nests and in complete nests tended to be larger than cells in incomplete or late season nests, despite the fact that the former tend to have more cells per nest than the later.

# MEAN CELL LENGTH *Megachile relativa*

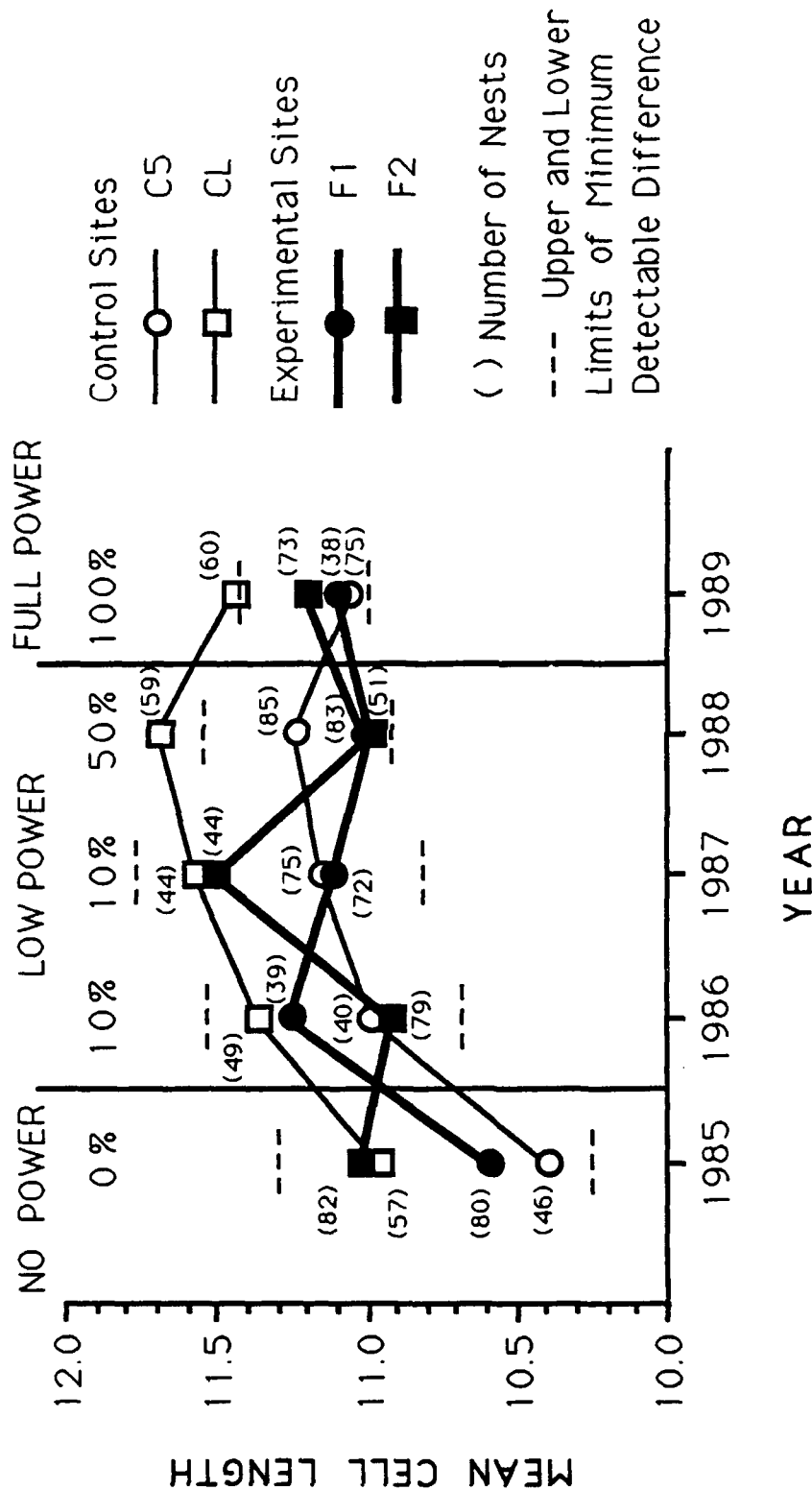


FIGURE 12. Mean cell length for *M. relativa* nests, 1985 - 1989, all cells. Numbers of nests in parenthesis; Horizontal dashes indicate upper and lower limits to the minimum detectable difference between experimental and control areas for each year.



TABLE 4: GLM of mean cell length for all cells from 1985-1989 M. relativa nests.

| CELL LENGTHS              |          |              |       |           |
|---------------------------|----------|--------------|-------|-----------|
| Source of variation       | df       | SS           | F     | P>F       |
| Year                      | 4        | 31.76        | 3.69  | 0.0385*   |
| Diameter                  | 1        | 20.02        | 30.34 | 0.0001*** |
| Exp                       | 1        | 3.24         | 0.39  | 0.5961    |
| Site[Exp]                 | 2        | 16.65        | 12.61 | 0.0001*** |
| Exp*Year                  | 4        | 9.26         | 0.28  | 0.8723    |
| Complete vs. incomplete   | 1        | 7.25         | 10.98 | 0.0009*   |
| Measurer[Yr]              | 11       | 23.66        | 3.26  | 0.0002**  |
| Cells per nest            | 1        | 36.52        | 55.35 | 0.0001*** |
| Early vs. Late Season     | 1        | 23.10        | 35.00 | 0.0001*** |
| Model                     | 26       | 185.46       | 7.13  | 0.0 ***   |
| Error                     | 1204     | 794.42       |       |           |
| $\bar{X} = 11.1\text{mm}$ | CV = 7.3 | $r^2 = 0.19$ |       |           |

TABLE 4 (continued)

| Parameter                       | Estimate      | T for $H_0$ :<br>Parameter = 0 | PR >  T         |
|---------------------------------|---------------|--------------------------------|-----------------|
| Yr: 1985                        | -0.3384       | -2.40                          | 0.0165*         |
| 1986                            | -0.1441       | -0.76                          | 0.4465          |
| 1987                            | -0.1811       | 1.28                           | 0.2020          |
| 1988                            | -0.1366       | -0.98                          | 0.3291          |
| 1989                            | 0.0           | --                             | --              |
| Diameter                        | -0.2234       | -5.51                          | 0.0001***       |
| Site C5                         | 0.0           | --                             | --              |
| CL                              | 0.3449        | 5.02                           | 0.0001***       |
| F1                              | 0.0031        | 0.04                           | 0.9645          |
| F2                              | 0.0           | --                             | --              |
| Complete vs.<br>Incomplete      | 0.1860<br>0.0 | 3.31<br>--                     | 0.0009**<br>--  |
| Cells per nest                  | -0.0819       | -7.44                          | 0.0001***       |
| Early Season vs.<br>Late Season | 0.2960<br>0.0 | 5.92<br>--                     | 0.0001***<br>-- |

The mean length of cells expected to have female offspring, and the mean length of cells expected to have male offspring were analyzed in separate GLM analyses (Tables 5, 6). Neither Exp nor Exp\*Year were significant in these analyses. However, separating cells by expected sex of offspring increased the proportion of the variance accounted for in the models. The model explained the highest proportion of the variance when only cells expected to have female offspring were included in the analysis, even though cells per nest and early vs. late season nests were the only effects that contribute significantly to variability in female cell lengths (Table 5). Cells expected to have female offspring averaged 0.7mm larger than cells expected to have male offspring (11.6mm vs. 10.9mm).

In the 1987 Annual Report, we expressed concern that bore diameters of 5.5 mm might bias the sex ratio towards males, since most females in 1986 nests were in larger diameters. Therefore, we added some 6.0mm nests in 1988. Our fears proved to be unfounded (Table 7, 8) since 1987 nests had sex ratios as low or lower than in previous years. Higher male biased sex ratios were produced in 1986 and 1988, when drought reduced flower populations, than in 1987 and 1989, when flowers were abundant. These results suggest that flower resource availability is more important than nest diameter in affecting M. relativa sex ratios. The results hold whether we consider secondary sex ratios (Table 7) or primary sex ratios (Table 8). Since 1990 had an abundance of flower bloom, we predict a continued low sex ratio for the 1990 nests.

**Within and Between Measurer Variability.** As mentioned earlier, differences between measurers usually contributed to the variance in mean cell lengths. Mean cell lengths for individual measurers varied from 10.62mm (ND, 1985) to 11.42mm (KS, 1988,1989) (Table 9). The range of means between measurers was greatest for 1986 cells, when four measurers were involved ( $11.26 - 10.75 = 0.51\text{mm}$ ). It decreased considerably for 1987 cells ( $11.32 - 11.22 = 0.10\text{mm}$ ), but increased again for 1988 cells ( $11.42 - 10.97 = 0.45\text{mm}$ ). In 1989, the differences between measurers decreased somewhat ( $11.42 - 11.03 = 0.39\text{mm}$ ).

In order to better understand the contribution of measurer differences to cell length variability, in 1987 39 M. relativa cells were measured up to three times by each measurer after the cell was originally measured. In an initial two-way model II ANOVA there was no significant interaction between measurers and cell measured. This indicates that although the mean cell length differed between measurers, the magnitude of the differences between cells was the same for all measurers.

The interaction and error variances were pooled by rerunning the ANOVA without including the interaction term in the model. This omission had the additional advantage that the residuals from the model

TABLE 5: GLM of mean cell lengths for 1985-1989 *M. relativa* nests; cells expected to have female offspring.

| CELL LENGTHS               |          |              |       |           |
|----------------------------|----------|--------------|-------|-----------|
| Source of variation        | df       | SS           | F     | P>F       |
| Year                       | 4        | 11.18        | 2.56  | 0.0979    |
| Diameter                   | 1        | 2.60         | 3.86  | 0.0507    |
| Exp                        | 1        | 3.81         | 3.90  | 0.1868    |
| Site[Exp]                  | 2        | 1.95         | 1.45  | 0.2372    |
| Exp*Year                   | 4        | 2.46         | 0.63  | 0.6895    |
| Complete vs.<br>incomplete | 1        | 0.42         | 0.63  | 0.4282    |
| Measurer[Yr]               | 11       | 12.00        | 1.62  | 0.0942    |
| Cells per nest             | 1        | 7.19         | 10.32 | 0.0015*   |
| Early vs. Late Season      | 1        | 16.65        | 24.71 | 0.0001*** |
| Model                      | 26       | 74.62        | 4.26  | 0.0001*** |
| Error                      | 234      | 157.72       |       |           |
| $\bar{X} = 11.6\text{mm}$  | CV = 7.1 | $r^2 = 0.32$ |       |           |

| Parameter                       | Estimate    | T for $H_0$ :<br>Parameter = 0 | PR >  T         |
|---------------------------------|-------------|--------------------------------|-----------------|
| Cells per Nest                  | -0.08       | -3.31                          | 0.0011*         |
| Early Season vs.<br>Late Season | 0.66<br>0.0 | 14.97<br>--                    | 0.0001***<br>-- |

TABLE 6: GLM of mean cell lengths for 1985 - 1989 *M. relativa* nests; cells expected to have male offspring.

| CELL LENGTHS               |          |              |       |           |
|----------------------------|----------|--------------|-------|-----------|
| Source of variation        | df       | SS           | F     | P>F       |
| Year                       | 4        | 21.95        | 2.56  | 0.0979    |
| Diameter                   | 1        | 17.46        | 29.80 | 0.0001*** |
| Exp                        | 1        | 5.05         | 0.65  | 0.5035    |
| Site[Exp]                  | 2        | 14.38        | 12.33 | 0.0001*** |
| Exp*Year                   | 4        | 5.07         | 0.18  | 0.9321    |
| Complete vs.<br>incomplete | 1        | 5.43         | 8.73  | 0.0032*   |
| Measurer[Yr]               | 11       | 23.57        | 3.66  | 0.0001*** |
| Cells per nest             | 1        | 28.11        | 48.02 | 0.0001*** |
| Early vs. Late Season      | 1        | 6.51         | 11.13 | 0.0009**  |
| Model                      | 26       | 133.42       | 8.77  | 0.0001*** |
| Error                      | 719      | 420.92       |       |           |
| $\bar{X} = 10.9\text{mm}$  | CV = 7.0 | $r^2 = 0.24$ |       |           |

| Parameter                       | Estimate      | T for H <sub>0</sub> :<br>Parameter = 0 | PR >  T        |
|---------------------------------|---------------|---|----------------|
| Site[Exp]                       |               |   |                |
| Site C5                         | 0.0           | --                                      | --             |
| CL                              | 0.4613        | 5.05                                    | 0.0001***      |
| F1                              | 0.0600        | 0.72                                    | 0.4701         |
| F2                              | 0.0           | --                                      | --             |
| Complete vs.<br>Incomplete      | 0.2290<br>0.0 | 3.05<br>--                              | 0.0024*<br>--  |
| Cells per nest                  | -0.0911       | 6.93                                    | 0.0001***      |
| Early Season vs.<br>Late Season | 0.2044<br>0.0 | 3.34<br>--                              | 0.0009**<br>-- |

Table 7: M. relativa secondary sex ratio by site and year.

| Site  | 1985  |         |       | 1986  |         |       |
|-------|-------|---------|-------|-------|---------|-------|
|       | Males | Females | Ratio | Males | Females | Ratio |
| C5    | 98    | 9       | 10.9  | 69    | 23      | 3.0   |
| CL    | 129   | 49      | 2.6   | 75    | 9       | 8.3   |
| F1    | 262   | 42      | 6.2   | 94    | 18      | 5.2   |
| F2    | 129   | 30      | 4.3   | 204   | 32      | 6.4   |
| Total | 618   | 130     | 4.8   | 442   | 82      | 5.4   |

| Site  | 1987  |         |       | 1988  |         |       |
|-------|-------|---------|-------|-------|---------|-------|
|       | Males | Females | Ratio | Males | Females | Ratio |
| C5    | 207   | 67      | 3.1   | 70    | 25      | 2.8   |
| CL    | 55    | 24      | 2.3   | 23    | 7       | 3.3   |
| F1    | 186   | 60      | 3.1   | 111   | 12      | 9.3   |
| F2    | 38    | 7       | 5.4   | 32    | 9       | 3.6   |
| Total | 486   | 158     | 3.1   | 236   | 53      | 4.5   |

| Site  | 1989  |         |       |
|-------|-------|---------|-------|
|       | Males | Females | Ratio |
| C5    | 148   | 70      | 2.1   |
| CL    | 54    | 35      | 1.5   |
| F1    | 95    | 18      | 5.3   |
| F2    | 101   | 21      | 4.8   |
| Total | 398   | 144     | 2.8   |

TABLE 8: M. relativa primary sex ratio by site and year.

| Site  | 1985  |         |       | 1986  |         |       |
|-------|-------|---------|-------|-------|---------|-------|
|       | Males | Females | Ratio | Males | Females | Ratio |
| C5    | 173.0 | 25.0    | 6.9   | 143.5 | 44.5    | 3.2   |
| CL    | 216.8 | 90.2    | 2.4   | 157.9 | 22.1    | 7.1   |
| F1    | 373.9 | 79.1    | 4.7   | 160.0 | 27.0    | 5.9   |
| F2    | 215.9 | 68.1    | 3.2   | 305.7 | 45.3    | 6.8   |
| Total | 979.6 | 262.4   | 3.7   | 767.1 | 138.9   | 5.5   |

| Site  | 1987  |         |       | 1988  |         |       |
|-------|-------|---------|-------|-------|---------|-------|
|       | Males | Females | Ratio | Males | Females | Ratio |
| C5    | 316.5 | 98.5    | 3.2   | 194.2 | 55.8    | 3.5   |
| CL    | 132.4 | 47.6    | 2.8   | 97.1  | 30.9    | 3.1   |
| F1    | 302.1 | 83.9    | 3.6   | 260.9 | 25.1    | 10.4  |
| F2    | 108.1 | 23.9    | 4.5   | 106.5 | 23.5    | 4.5   |
| Total | 859.1 | 253.9   | 3.4   | 658.7 | 135.3   | 4.9   |

| Site  | 1989  |         |       |
|-------|-------|---------|-------|
|       | Males | Females | Ratio |
| C5    | 251.2 | 107.8   | 2.3   |
| CL    | 123.3 | 66.7    | 1.9   |
| F1    | 145.3 | 23.7    | 6.1   |
| F2    | 189.9 | 53.1    | 3.6   |
| Total | 709.7 | 251.3   | 2.8   |

TABLE 9: Differences between measurers in mean cell lengths for M. relativa.

| Measurer  | Mean<br>Cell Lengths<br>m m | No. Nests<br>Measured |
|-----------|-----------------------------|-----------------------|
| ER (1985) | 10.77                       | 85                    |
| ND (1985) | 10.62                       | 99                    |
| KS (1985) | 10.94                       | 81                    |
| JZ (1986) | 11.26                       | 64                    |
| KS (1986) | 11.22                       | 58                    |
| LS (1986) | 10.75                       | 49                    |
| MS (1986) | 11.07                       | 36                    |
| KS (1987) | 11.26                       | 99                    |
| LS (1987) | 11.22                       | 28                    |
| VS (1987) | 11.32                       | 108                   |
| BZ (1988) | 10.97                       | 68                    |
| KS (1988) | 11.42                       | 79                    |
| VS (1988) | 11.22                       | 131                   |
| BZ (1989) | 11.03                       | 79                    |
| KS (1989) | 11.42                       | 83                    |
| VS (1989) | 11.13                       | 84                    |



were normally distributed, whereas with the interaction term the residuals were not normally distributed. Each person measured each cell an average of 2.55 times; this value was used to compute the relative contribution of within- and between- measurer variance to the total variance (Table 10). 75% of the variance was between cells, while only 25% was between and within measurers. Variance within measurers (15%) accounted for more of the measurer variance than did variance between measurers (10%). In this analysis the mean cell length was 10.5mm, and the overall coefficient of variation was only 3.6%, or a standard deviation of 0.4mm. Measurer variance accounts for 25% of the total variance, and thus 50% of the standard deviation = .2mm. In the full analysis, the overall mean cell length was 11.1mm with a CV of 7.3%, or a standard deviation of about 0.8mm. Thus, our analysis suggests that measurer variance accounts for about 0.4mm.

Because the contribution of the within-measurer component of variance is greater than the between-measurer contribution, and the sum of both components accounts for a small percent of the variance and a small absolute amount of variation, we concluded in the 1988 Annual Report that further steps to reduce this variance are unnecessary. However, in light of the increase in discrepancy between measurers of 1988 nests, we were careful in 1990 to compare our measurement techniques in order to decrease discrepancies. This extra effort seems to have helped.

### M. inermis

As with M. relativa nests, mean cell length was calculated for each nest and used in GLM analysis. However, in some years, numbers of nests are very low at some sites (eg., 1 nest at the CL site in 1986 and 1988). Therefore, cell length data were pooled for pre-operational years (1985-1987 or 1985-1988) and operational years (1988-1989 or 1989). Only nests with diameters greater than 9.5mm were used in the analysis. When all cells are analyzed the residuals are significantly different from normal ( $P < 0.01$ ). When cells with male and female offspring are analyzed separately, the residuals are not significantly different from normal ( $P > .15$ ) except for pooled 88-89 male cells ( $P < 0.03$ ).

If ELF EM fields have an effect on M. inermis cell lengths we would expect to see mean cell lengths changing for the treatment sites but not for the control sites during operational years. This does not seem to be the case. Control sites tended to have larger cells than Experimental sites during pre-operational years, and changes when the antenna became operational were as great or greater for control sites as for experimental sites (Fig. 13). Variability within the control areas, and to a lesser extent

TABLE 10: Two-Way, Model II ANOVA partitioning the variance in cell length within- and between- measurer.

CELL LENGTHS

| Source of Variance                                | DF                                   | MS    | F     | P>F       |
|---|--------------------------------------|-------|-------|-----------|
| Between Measurers                                 | 3                                    | 9.587 | 65.39 | 0.0001*** |
| Between Cells                                     | 38                                   | 7.540 | 51.42 | 0.0000*** |
| Within Measurer (Error)                           | 355                                  | 0.147 |       |           |
| $\bar{X} = 10.5\text{mm}$ $CV = 3.6$ $r^2 = 0.86$ |                                      |       |       |           |
| Between Measurers                                 | $s^2 + 2.55s_{mc}^2 + 39(2.55)s_m^2$ |       | 0.095 | 9.8%      |
| Between Cells                                     | $s^2 + 2.55s_{mc}^2 + 4(2.55)s_c^2$  |       | 0.725 | 75.0%     |
| Within Measurer Error)                            | $s^2 + 2.55s_{mc}^2$                 |       | 0.147 | 15.2%     |

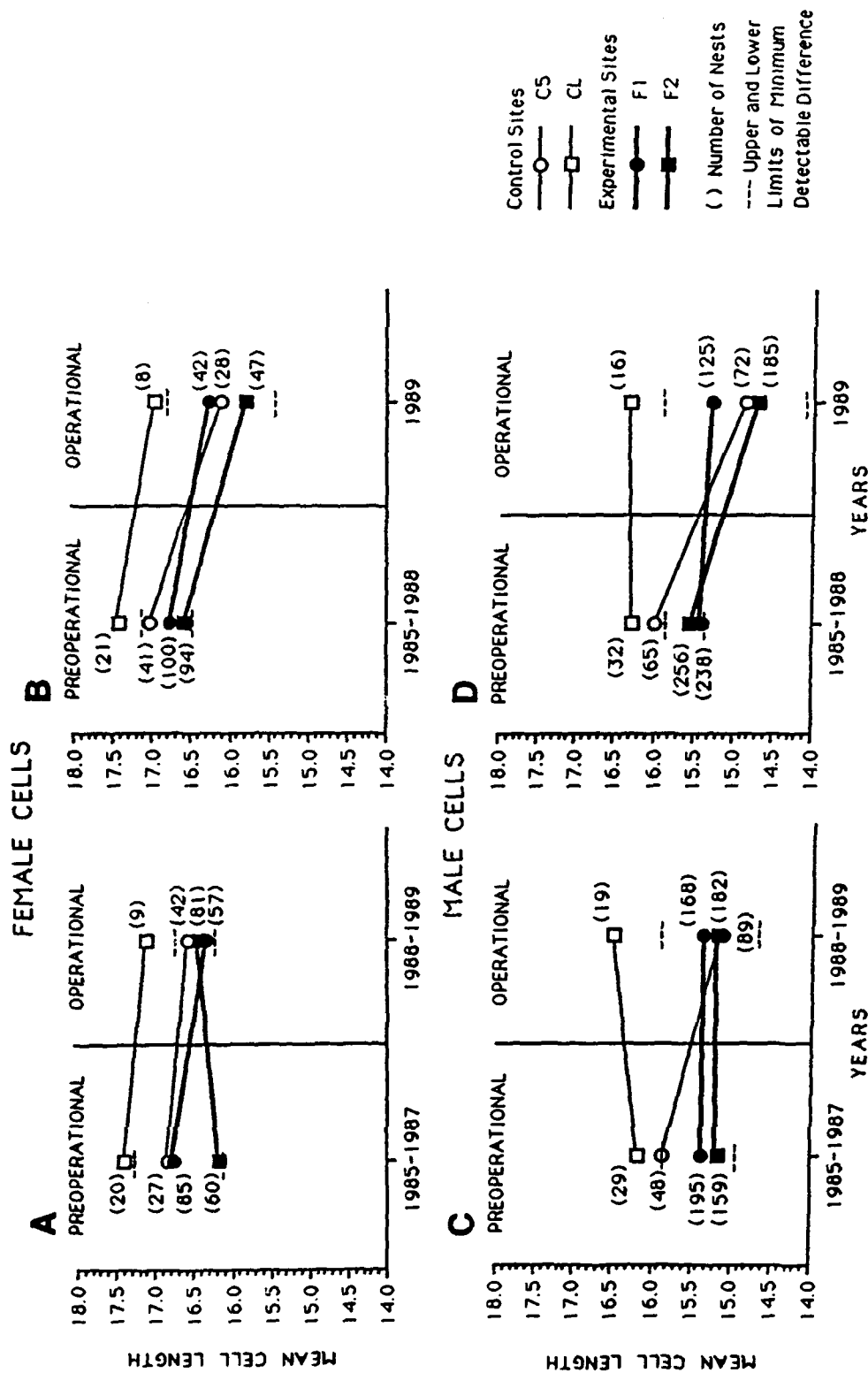


FIGURE 13. Mean cell length for *M. inermis* nests, diameters > 9.5 mm. A: Cells expected to be female; 1985-1987 vs. 1988-1989. B: Cells expected to be female; 1985-1988 vs. 1989. C: Cells expected to be male; 1985-1987 vs. 1988-1989. D: Cells expected to be male; 1985-1988 vs. 1989. Numbers of nests in parenthesis; Horizontal dashes indicate upper and lower limits to the minimum detectable difference between experimental and control areas for each year.

TABLE 11a: GLM of mean cell lengths for M. inermis nests; cells expected to have female offspring, pooled pre-operational vs. operational years, diameters > 9.5mm.

CELL LENGTHS

| Source of variation       | df       | SS           | F     | P>F       |
|---------------------------|----------|--------------|-------|-----------|
| Year (85-87 vs 88-89)     | 1        | 0.34         | 0.02  | 0.8901    |
| Diameter                  | 1        | 0.50         | 0.41  | 0.5203    |
| Exp                       | 1        | 7.77         | 2.04  | 0.2897    |
| Site[Exp]                 | 2        | 7.63         | 3.19  | 0.0424*   |
| Exp*Year                  | 1        | 0.53         | 0.14  | 0.7444    |
| Complete vs. incomplete   | 1        | 16.15        | 13.49 | 0.0003*** |
| Measurer[Yr]              | 6        | 97.67        | 13.59 | 0.0001*** |
| Cells per nest            | 1        | 33.41        | 27.90 | 0.0001*** |
| Early vs. Late Season     | 1        | 1.76         | 1.47  | 0.2258    |
| Bore Depth                | 1        | 0.59         | 0.49  | 0.4833    |
| Bore Depth*Year           | 1        | 0.29         | 0.24  | 0.6258    |
| Diameter*Bore depth       | 1        | 0.49         | 0.41  | 0.5231    |
| Diameter*Year*            |          |              |       |           |
| Bore Depth                | 1        | 0.23         | 0.19  | 0.6599    |
| Diameter*Year             | 1        | 0.28         | 0.23  | 0.6299    |
| Model                     | 20       | 219.77       | 9.18  | 0.0001*** |
| Error                     | 360      | 431.10       |       |           |
| $\bar{X} = 16.6\text{mm}$ | CV = 6.6 | $r^2 = 0.34$ |       |           |

| Parameter               | Estimate | T for H <sub>0</sub> :<br>Parameter = 0 | PR >  T   |
|-------------------------|----------|---|-----------|
| Site[Exp] C5            | 0.0      | --                                      | --        |
| CL                      | 0.5042   | 1.95                                    | 0.0522    |
| F1                      | 0.2185   | 1.58                                    | 0.1141    |
| F2                      | 0.0      | --                                      | --        |
| Complete vs. Incomplete | 0.7917   | 3.67                                    | 0.0003*** |
|                         | 0.0      | --                                      | --        |
| Cells per nest          | -0.3159  | -5.28                                   | 0.0001*** |

TABLE 11b: GLM of mean cell lengths for M. inermis nests; cells expected to have female offspring, pooled pre-operational vs. operational years, diameters > 9.5mm.

| CELL LENGTHS              |          |              |       |           |
|---------------------------|----------|--------------|-------|-----------|
| Source of variation       | df       | SS           | F     | P>F       |
| Year (85-88 vs 89)        | 1        | 0.51         | 0.04  | 0.8554    |
| Diameter                  | 1        | 0.61         | 0.54  | 0.4639    |
| Exp                       | 1        | 7.45         | 1.56  | 0.3384    |
| Site[Exp]                 | 1        | 9.57         | 4.21  | 0.0156*   |
| Exp*Year                  | 1        | 0.06         | 0.01  | 0.9241    |
| Complete vs. incomplete   | 1        | 16.58        | 14.58 | 0.0002*** |
| Measurer[Yr]              | 7        | 100.14       | 12.58 | 0.0001*** |
| Cells per nest            | 1        | 35.31        | 31.06 | 0.0001*** |
| Early vs. Late Season     | 1        | 1.71         | 1.51  | 0.2205    |
| Bore Depth                | 1        | 0.60         | 0.52  | 0.4696    |
| Bore Depth*Year           | 1        | 0.48         | 0.42  | 0.5162    |
| Diameter*Bore depth       | 1        | 0.60         | 0.53  | 0.4674    |
| Diameter*Year*            |          |              |       |           |
| Bore Depth                | 1        | 0.50         | 0.44  | 0.5073    |
| Diameter*Year             | 1        | 0.53         | 0.47  | 0.4951    |
| Model                     | 21       | 242.71       | 10.17 | 0.0001*** |
| Error                     | 359      | 408.16       |       |           |
| $\bar{X} = 16.6\text{mm}$ | CV = 6.4 | $r^2 = 0.37$ |       |           |

| Parameter               | Estimate | T for H <sub>0</sub> :<br>Parameter = 0 | PR >  T   |
|-------------------------|----------|---|-----------|
| Site[Exp] C5            | 0.0      | --                                      | --        |
| CL                      | 0.5609   | 2.28                                    | 0.0232*   |
| F1                      | 0.2322   | 1.77                                    | 0.0782    |
| F2                      | 0.0      | --                                      | --        |
| Complete vs. Incomplete | 0.8059   | 3.82                                    | 0.0002*** |
|                         | 0.0      | --                                      | --        |
| Cells per nest          | -0.3149  | -5.57                                   | 0.0001*** |

TABLE 12a: GLM of mean cell lengths for M. inermis nests; cells expected to have male offspring; pooled pre-operational vs. operational years; diameters >9.5mm.

CELL LENGTHS

| Source of variation       | df       | SS           | F      | P>F       |
|---------------------------|----------|--------------|--------|-----------|
| Year (85-87 vs 88-89)     | 1        | 0.93         | 0.02   | 0.8987    |
| Diameter                  | 1        | 0.85         | 0.93   | 0.3344    |
| Exp                       | 1        | 20.64        | 1.81   | 0.3106    |
| Site[Exp]                 | 2        | 22.78        | 12.43  | 0.0001*** |
| Exp*Year                  | 1        | 6.40         | 0.56   | 0.5318    |
| Complete vs. incomplete   | 1        | 19.90        | 21.71  | 0.0001*** |
| Measurer[Yr]              | 6        | 316.38       | 57.53  | 0.0 ***   |
| Cells per nest            | 1        | 128.94       | 140.67 | 0.0001*** |
| Early vs. Late Season     | 1        | 0.26         | 0.29   | 0.5913    |
| Bore Depth                | 1        | 0.69         | 0.75   | 0.3863    |
| Bore Depth*Year           | 1        | 0.88         | 0.02   | 0.9013    |
| Diameter*Bore depth       | 1        | 0.89         | 0.97   | 0.3244    |
| Diameter*Year*            |          |              |        |           |
| Bore Depth                | 1        | 1.02         | 0.02   | 0.8939    |
| Diameter*Year             | 1        | 1.08         | 0.02   | 0.8911    |
| Model                     | 20       | 638.81       | 31.94  | 0.0***    |
| Error                     | 988      | 1526.08      |        |           |
| <hr/>                     |          |              |        |           |
| $\bar{X} = 15.3\text{mm}$ | CV = 6.2 | $r^2 = 0.42$ |        |           |

| Parameter               | Estimate | T for $H_0$ :<br>Parameter = 0 | PR >  T   |
|-------------------------|----------|--------------------------------|-----------|
| Site[Exp] C5            | 0.0      | --                             | --        |
| CL                      | 0.6489   | 3.90                           | 0.0001*** |
| F1                      | 0.2157   | 3.03                           | 0.0025*   |
| F2                      | 0.0      | --                             | --        |
| Complete vs. Incomplete | 0.4975   | 4.66                           | 0.0001*** |
|                         | 0.0      | --                             | --        |
| Cells per nest          | -0.3444  | -11.86                         | 0.0001*** |

TABLE 12b: GLM of mean cell lengths for *M. inermis* nests; cells expected to have male offspring; pooled pre-operational vs. operational years; diameters >9.5mm.

CELL LENGTHS

| Source of variation          | df       | SS           | F      | P>F       |
|------------------------------|----------|--------------|--------|-----------|
| Year (85-88 vs 89)           | 1        | 0.83         | 0.02   | 0.8953    |
| Diameter                     | 1        | 0.87         | 1.01   | 0.3149    |
| Exp                          | 1        | 17.83        | 1.41   | 0.3572    |
| Site[Exp]                    | 2        | 25.32        | 14.73  | 0.0001*** |
| Exp*Year                     | 1        | 5.40         | 0.43   | 0.5808    |
| Complete vs. incomplete      | 1        | 21.57        | 25.09  | 0.0001*** |
| Measurer[Yr]                 | 7        | 310.96       | 51.68  | 0.0 ***   |
| Cells per nest               | 1        | 138.06       | 160.61 | 0.0001*** |
| Early vs. Late Season        | 1        | 0.10         | 0.12   | 0.7304    |
| Bore Depth                   | 1        | 0.88         | 1.03   | 0.3112    |
| Bore Depth*Year              | 1        | 0.89         | 0.02   | 0.8916    |
| Diameter*Bore depth          | 1        | 0.87         | 1.01   | 0.3158    |
| Diameter*Year                | 1        | 0.87         | 0.02   | 0.8929    |
| Diameter*Year*<br>Bore Depth | 1        | 0.93         | 0.02   | 0.8889    |
| Model                        | 21       | 694.83       | 33.09  | 0.0 ***   |
| Error                        | 967      | 831.25       |        |           |
| $\bar{X} = 15.3\text{mm}$    | CV = 6.0 | $r^2 = 0.46$ |        |           |

| Parameter                  | Estimate      | T for $H_0$ :<br>Parameter = 0 | PR >  T         |
|----------------------------|---------------|--------------------------------|-----------------|
| Site[Exp] C5               | 0.0           | --                             | --              |
| CL                         | 0.6211        | 3.90                           | 0.0001***       |
| F1                         | 0.2536        | 3.73                           | 0.0002***       |
| F2                         | 0.0           | --                             | --              |
| Complete vs.<br>Incomplete | 0.5177<br>0.0 | 5.01<br>--                     | 0.0001***<br>-- |
| Cells per nest             | -0.3500       | -12.61                         | 0.0001***       |

within the experimental areas is great, so differences between experimental and control areas is not expected to be significant. Minimum detectable differences tend to be large, especially for operational years. GLM analyses (Tables 11, 12) confirm that neither Exp nor Exp\*Year contribute significantly to variation in mean cell length. Therefore, there does not yet appear to be any influence of ELF EM fields on cell length for this species. However, it is possible that differences in mean cell length will be detected in future years if gradual genetic changes are occurring at the experimental areas.

M. inermis cells expected to have female offspring averaged 1.3mm larger than cells expected to have male offspring (16.6mm - 15.3mm). The models accounted for 34-37% of the variance in mean female cell lengths and 42-46% of the variance in male cell lengths. Between nest variability (error ms) is less than for M. relativa. Parameters that contributed significantly to M. inermis cell length were very similar to those that were significant for M. relativa cell length. Cells from the CL site tended to be slightly but significantly larger than cells from other sites. Cell lengths decreased slightly as number of cells in a nest increased. Cells in complete nests tended to be larger than cells in incomplete nests.

As with M. relativa, differences between measurers (measurer [yr]) made a significant contribution to cell lengths. Cells measured by KS were larger than cells measured by other measurers (Table 13). In 1990, 39 M. inermis cells were measured three times by each measurer after the cell was originally measured. A two-way random-effects model ANOVA will be used, as for M. relativa, to partition the variance within and between measurers and between cells. We have not completed this analysis as of this writing.

Sex ratios for M. inermis vary considerably between sites and years (Table 14, 15), and do not show as clear an influence of climate and floral resources as sex ratios for M. relativa. During 1985 and 1986, high sex ratios may have been an artifact of short bore depths (Stephen and Osgood, 1965). Sex ratios were generally higher in the drought year of 1988 than in 1987, perhaps due to reduced resource levels, but were also high at some sites in 1989 when resource levels were high.

**Offspring Weights.** In the 1987 Annual Report we questioned the necessity to analyze the variance in cell volumes, because volumes are highly correlated with nest diameters. We suggested that the answer to this question depended on whether offspring weights correlate best with cell length or with cell volume. Dry weights of some M. relativa offspring from 1986 nests were measured in hopes of addressing this question. Furthermore, both live and dry weights of a sample of both species from



TABLE 13: Differences between observers in mean male cell lengths for M. inermis, bore diameters >9.5.

| Measurer  | Mean<br>Cell Lengths<br>m m | No. Nests<br>Measured |
|-----------|-----------------------------|-----------------------|
| LS (1985) | 14.87                       | 91                    |
| MS (1985) | 14.92                       | 37                    |
| JZ (1986) | 15.75                       | 21                    |
| KS (1986) | 16.39                       | 18                    |
| LS (1986) | 14.06                       | 16                    |
| MS (1986) | 15.38                       | 12                    |
| KS (1987) | 16.30                       | 99                    |
| LS (1987) | 15.09                       | 36                    |
| VS (1987) | 15.22                       | 101                   |
| BZ (1988) | 15.36                       | 23                    |
| KS (1988) | 17.11                       | 50                    |
| VS (1988) | 15.57                       | 87                    |
| BZ (1989) | 14.38                       | 102                   |
| KS (1989) | 15.80                       | 97                    |
| VS (1989) | 14.89                       | 199                   |

Table 14: *M. inermis* secondary sex ratio by site and year.

| Site  | 1985  |         |       | 1986  |         |       |
|-------|-------|---------|-------|-------|---------|-------|
|       | Males | Females | Ratio | Males | Females | Ratio |
| C5    | 27    | 7       | 3.9   | 35    | 10      | 3.5   |
| CL    | 25    | 12      | 2.1   | 6     | 2       | 3.0   |
| F1    | 322   | 22      | 14.6  | 80    | 17      | 4.7   |
| F2    | 140   | 37      | 3.8   | 180   | 29      | 6.2   |
| Total | 514   | 78      | 6.6   | 301   | 58      | 5.2   |

| Site  | 1987  |         |       | 1988  |         |       |
|-------|-------|---------|-------|-------|---------|-------|
|       | Males | Females | Ratio | Males | Females | Ratio |
| C5    | 104   | 36      | 2.9   | 46    | 26      | 1.8   |
| CL    | 46    | 29      | 1.6   | 8     | 1       | 8.0   |
| F1    | 315   | 142     | 2.2   | 132   | 27      | 4.9   |
| F2    | 295   | 79      | 3.7   | 262   | 65      | 4.0   |
| Total | 760   | 286     | 2.7   | 448   | 119     | 3.8   |

| Site  | 1989  |         |       |
|-------|-------|---------|-------|
|       | Males | Females | Ratio |
| C5    | 194   | 48      | 4.0   |
| CL    | 35    | 15      | 2.3   |
| F1    | 354   | 90      | 3.9   |
| F2    | 556   | 93      | 6.0   |
| Total | 1139  | 246     | 4.6   |

TABLE 15: M. inermis primary sex ratio by site and year.

| Site  | 1985  |         |       | 1986  |         |       |
|-------|-------|---------|-------|-------|---------|-------|
|       | Males | Females | Ratio | Males | Females | Ratio |
| C5    | 56.6  | 17.4    | 3.3   | 49.8  | 16.2    | 3.1   |
| CL    | 39.6  | 26.4    | 1.5   | 6     | 2       | 3.0   |
| F1    | 503.9 | 56.1    | 9.0   | 127.2 | 42.8    | 3.0   |
| F2    | 222.5 | 65.5    | 3.4   | 251.9 | 42.1    | 6.0   |
| Total | 822.6 | 165.4   | 5.0   | 434.9 | 103.1   | 4.2   |

| Site  | 1987   |         |       | 1988  |         |       |
|-------|--------|---------|-------|-------|---------|-------|
|       | Males  | Females | Ratio | Males | Females | Ratio |
| C5    | 185.7  | 66.3    | 2.8   | 73.4  | 42.6    | 1.7   |
| CL    | 73.8   | 39.2    | 1.9   | 14    | 6       | 2.3   |
| F1    | 431.4  | 189.6   | 2.3   | 191.6 | 44.2    | 4.3   |
| F2    | 444.1  | 108.9   | 4.1   | 446.2 | 111.8   | 4.0   |
| Total | 1135.0 | 404.0   | 2.8   | 725.2 | 204.6   | 3.5   |

| Site  | 1989   |         |       |
|-------|--------|---------|-------|
|       | Males  | Females | Ratio |
| C5    | 344.7  | 108.3   | 3.2   |
| CL    | 66.0   | 30.1    | 2.2   |
| F1    | 621.7  | 185.3   | 3.4   |
| F2    | 1027.7 | 215.3   | 4.8   |
| Total | 2060.1 | 539.0   | 3.8   |

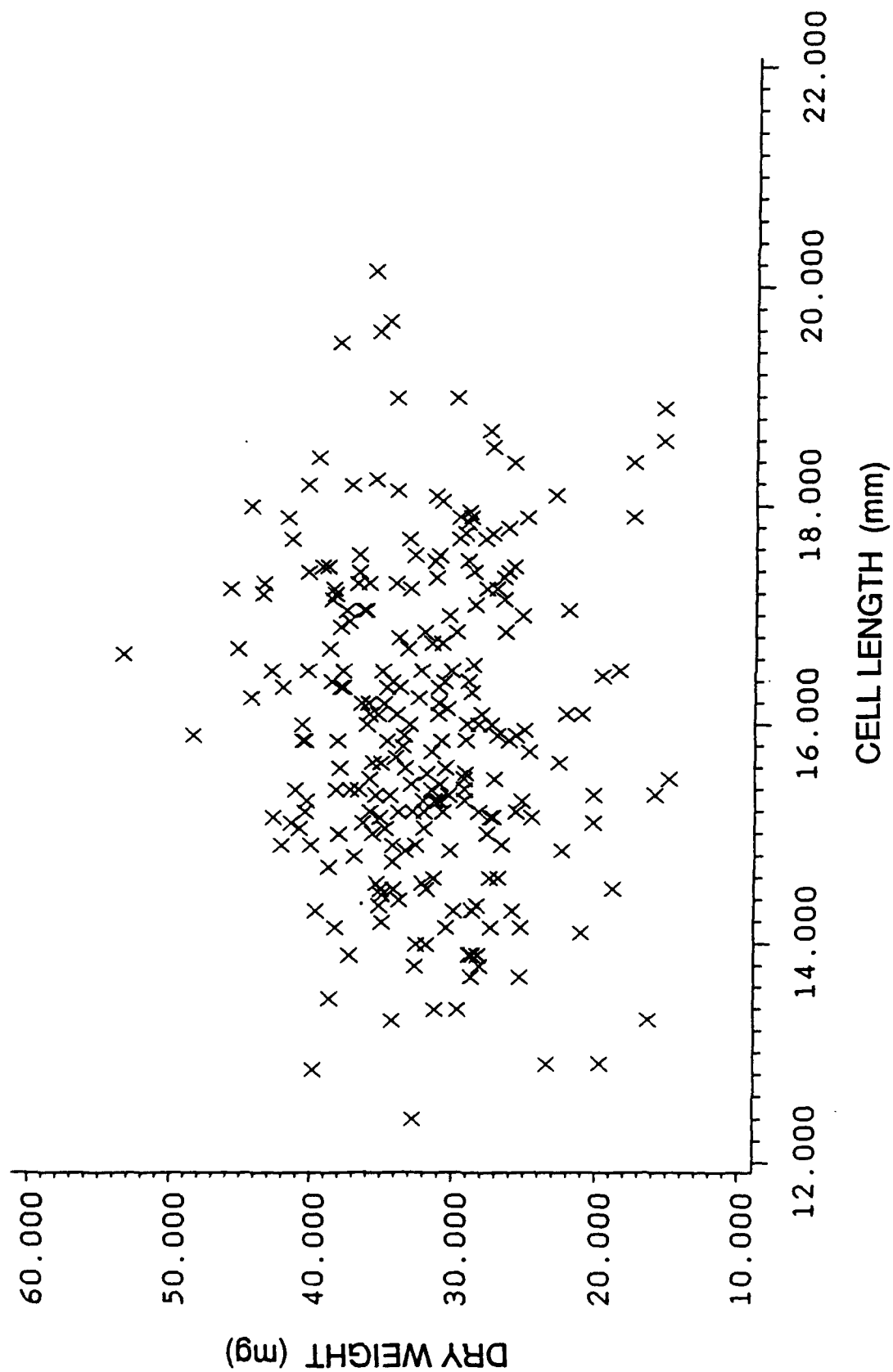


FIGURE 14. Male *M. inermis* dry weight vs. cell length, 1988.

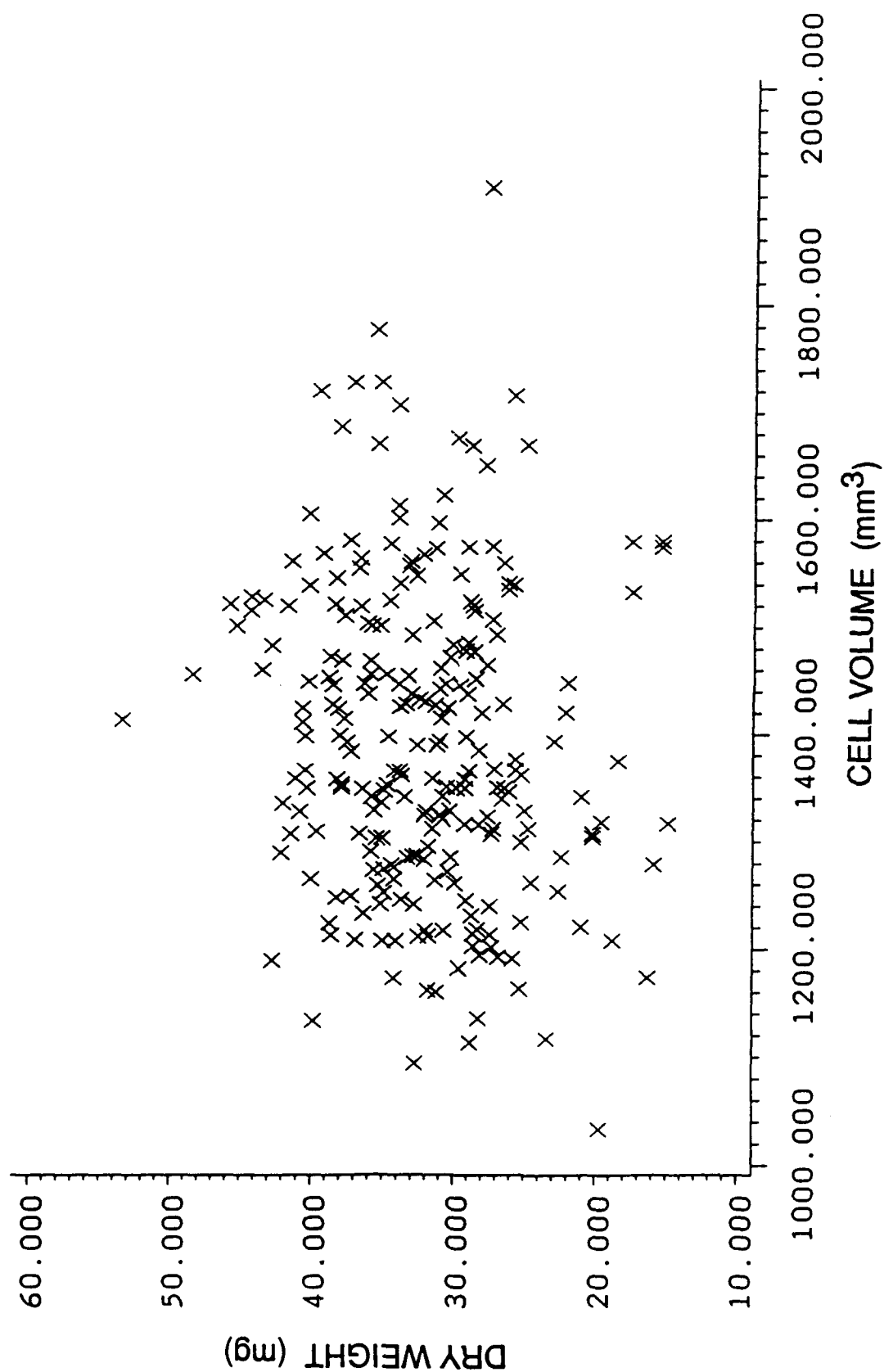


FIGURE 15. Male *M. inermis* dry weight vs. cell volume, 1988.

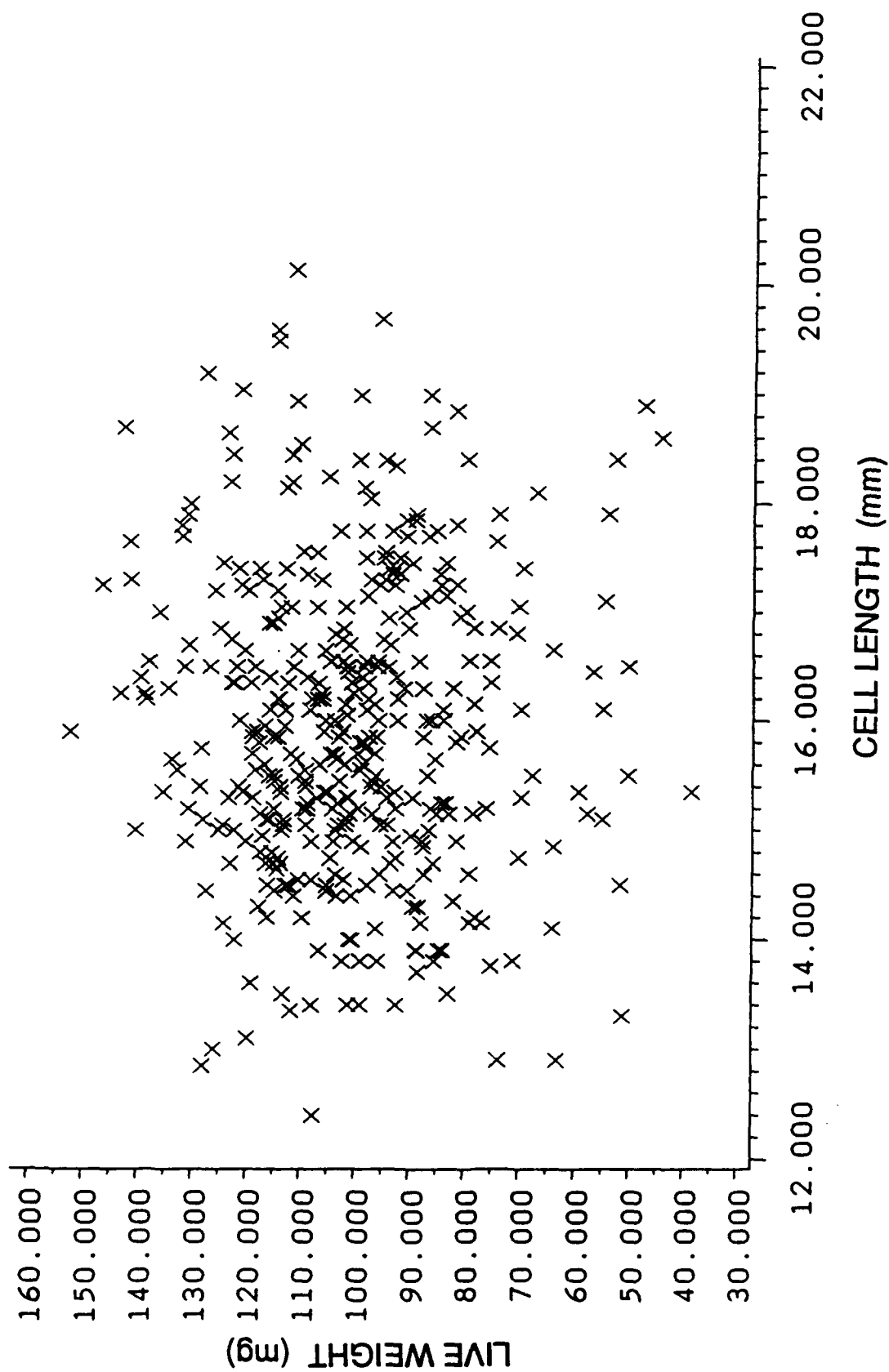


FIGURE 16. Male *M. inermis* live weight vs. cell length, 1988.

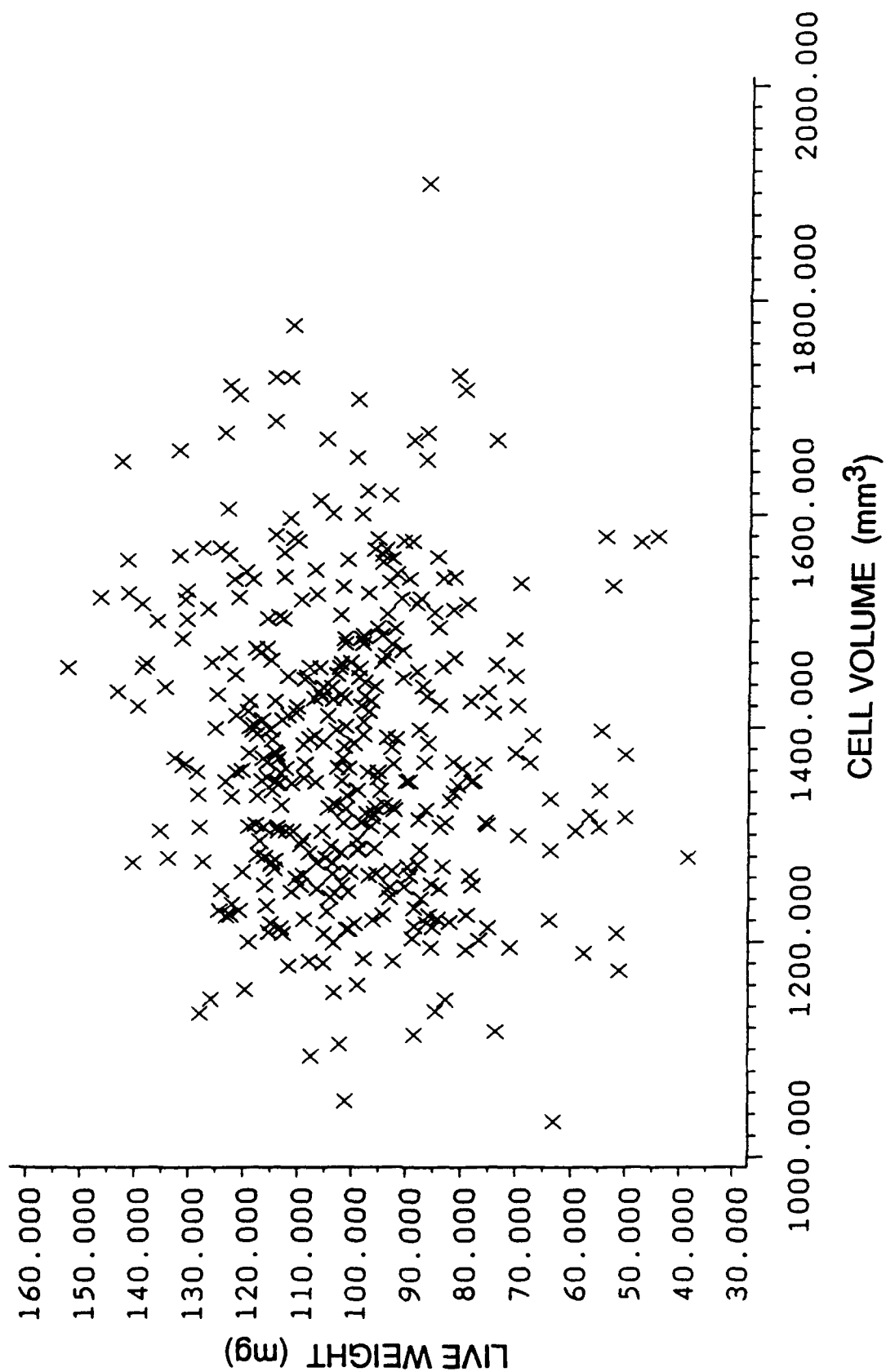


FIGURE 17. Male *M. inermis* live weight vs. cell volume, 1988.

TABLE 16: M. relativa Weights by Sex, Site and Year.

| $\overline{\text{mg}} \pm \text{S.D.}$<br>(N) |                        |                        |                        |                        |                        |
|---|------------------------|------------------------|------------------------|------------------------|------------------------|
| Female  |                        |                        |                        |                        |                        |
| YEAR  | C5                     | CL                     | F1                     | F2                     | TOTAL                  |
| Dry Weights                                   |                        |                        |                        |                        |                        |
| 1986  | $14.6 \pm 2.6$<br>(8)  | $13.5 \pm 1.5$<br>(3)  | $14.9 \pm 4.7$<br>(11) | $14.8 \pm 3.5$<br>(18) | $14.7 \pm 3.5$<br>(40) |
| 1987  | $15.2 \pm 2.2$<br>(26) | $14.1 \pm 2.3$<br>(11) | $15.7 \pm 1.5$<br>(36) | $15.8 \pm 1.5$<br>(6)  | $15.4 \pm 1.9$<br>(79) |
| 1988  | $12.4 \pm 2.8$<br>(6)  | $10.6 \pm 0.8$<br>(3)  | $10.8 \pm 3.1$<br>(7)  | $13.3 \pm 3.6$<br>(5)  | $11.8 \pm 2.9$<br>(21) |
| Live Weights                                  |                        |                        |                        |                        |                        |
| 1987  | $41.5 \pm 5.8$<br>(18) | $44.6 \pm 5.1$<br>(6)  | $43.6 \pm 5.3$<br>(19) | $45.4 \pm 3.7$<br>(4)  | $43.1 \pm 5.4$<br>(47) |
| 1988  | $39.8 \pm 6.3$<br>(23) | $33.8 \pm 3.2$<br>(7)  | $31.5 \pm 10.6$<br>(8) | $38.9 \pm 8.3$<br>(9)  | $37.3 \pm 7.8$<br>(47) |



TABLE 16 continued

| $\overline{\text{mg}} \pm \text{S.D.}$<br>(N) |                        |                        |                         |                        |                         |
|---|------------------------|------------------------|-------------------------|------------------------|-------------------------|
| Male  |                        |                        |                         |                        |                         |
| YEAR  | C5                     | CL                     | F1                      | F2                     | TOTAL                   |
| Dry Weights                                   |                        |                        |                         |                        |                         |
| 1986  | $10.9 \pm 2.5$<br>(34) | $10.2 \pm 2.3$<br>(28) | $10.8 \pm 3.2$<br>(27)  | $11.9 \pm 2.5$<br>(86) | $11.3 \pm 2.6$<br>(175) |
| 1987  | $12.3 \pm 2.3$<br>(89) | $11.4 \pm 2.3$<br>(35) | $12.2 \pm 2.0$<br>(95)  | $11.5 \pm 2.5$<br>(26) | $12.1 \pm 2.2$<br>(245) |
| 1988  | $8.6 \pm 1.7$<br>(51)  | $9.2 \pm 1.9$<br>(12)  | $9.6 \pm 1.9$<br>(63)   | $8.5 \pm 1.4$<br>(20)  | $9.1 \pm 1.8$<br>(146)  |
| Live Weights                                  |                        |                        |                         |                        |                         |
| 1987  | $35.5 \pm 5.2$<br>(73) | $32.6 \pm 5.7$<br>(25) | $35.5 \pm 4.5$<br>(112) | $33.2 \pm 6.4$<br>(33) | $34.9 \pm 5.2$<br>(243) |
| 1988  | $27.7 \pm 4.6$<br>(63) | $27.7 \pm 4.8$<br>(22) | $31.0 \pm 5.8$<br>(106) | $28.5 \pm 4.4$<br>(29) | $29.4 \pm 5.4$<br>(220) |

TABLE 17: M. inermis Weights by Sex, Site and Year.

| $\overline{\text{mg}} \pm \text{S.D.}$<br>(N) |                          |                        |                          |                          |                           |
|---|--------------------------|------------------------|--------------------------|--------------------------|---------------------------|
| Female  |                          |                        |                          |                          |                           |
| YEAR  | C5                       | CL                     | F1                       | F2                       | TOTAL                     |
| Dry Weights                                   |                          |                        |                          |                          |                           |
| 1986  | 46.0 $\pm$ 6.0<br>(4)    | 64.0 $\pm$ 18.8<br>(5) | 58.5<br>(1)              | —*                       | 56.3 $\pm$ 15.8<br>(10)   |
| 1987  | 49.3 $\pm$ 19.3<br>(12)  | 50.1 $\pm$ 10.9<br>(6) | 57.3 $\pm$ 9.9<br>(51)   | 54.2 $\pm$ 12.4<br>(21)  | 55.0 $\pm$ 12.3<br>(90)   |
| 1988  | 51.7 $\pm$ 3.8<br>(4)    | —*                     | 51.9 $\pm$ 5.0<br>(5)    | 44.8 $\pm$ 9.5<br>(18)   | 47.1 $\pm$ 8.7<br>(27)    |
| Live Weights                                  |                          |                        |                          |                          |                           |
| 1987  | —*                       | —*                     | 181.7 $\pm$ 16.1<br>(9)  | 159.4 $\pm$ 38.8<br>(8)  | 171.2 $\pm$ 30.3<br>(17)  |
| 1988  | 149.4 $\pm$ 22.4<br>(24) | 159.4<br>(1)           | 150.2 $\pm$ 22.1<br>(23) | 146.8 $\pm$ 27.0<br>(63) | 148.2 $\pm$ 24.8<br>(111) |

\* No bees weighed.

TABLE 17 continued.

| $\overline{\text{mg}} \pm \text{S.D.}$<br>(N) |                         |                        |                          |                           |                           |
|---|-------------------------|------------------------|--------------------------|---------------------------|---------------------------|
| Male  |                         |                        |                          |                           |                           |
| YEAR  | C5                      | CL                     | F1                       | F2                        | TOTAL                     |
| Dry Weights                                   |                         |                        |                          |                           |                           |
| 1986  | $29.0 \pm 5.4$<br>(4)   | —*                     | $37.2 \pm 10.2$<br>(29)  | $39.6 \pm 7.7$<br>(47)    | $38.2 \pm 8.8$<br>(80)    |
| 1987  | $37.7 \pm 7.4$<br>(29)  | $37.5 \pm 6.0$<br>(15) | $38.4 \pm 6.9$<br>(144)  | $37.6 \pm 6.6$<br>(79)    | $38.0 \pm 6.8$<br>(297)   |
| 1988  | $31.0 \pm 5.6$<br>(20)  | $31.0 \pm 3.7$<br>(6)  | $31.6 \pm 6.7$<br>(74)   | $32.6 \pm 6.3$<br>(143)   | $32.1 \pm 6.3$<br>(243)   |
| Live Weights                                  |                         |                        |                          |                           |                           |
| 1987  | $100.6 \pm 22.8$<br>(7) | —*                     | $111.7 \pm 19.1$<br>(39) | $112.1 \pm 22.6$<br>(46)  | $111.1 \pm 21.2$<br>(92)  |
| 1988  | $97.1 \pm 16.9$<br>(43) | $95.8 \pm 11.7$<br>(8) | $98.5 \pm 18.0$<br>(118) | $103.7 \pm 20.3$<br>(227) | $101.3 \pm 19.3$<br>(396) |

1987 - 1989 nests were measured. Dry weights for bees from 1989 nests are still being measured as of this writing.

Figures 14 - 17 plot dry weight or live weight of male M. inermis vs. cell length or cell volume. Bee weight appears to be unrelated to cell length or volume, and thus does not help us resolve the question of whether we should be analyzing variance in cell volume rather than cell length. Since the two measures are correlated, and since our analyses have thus far been on cell length, we will continue to analyze only cell length in the future. However, we should be able to do a separate GLM analysis of bee weight as a dependent variable, just as we have analyzed cell length, for 1987-1989 bees. Such an analysis has not yet been done. It will add an additional hypothesis to our study: **Newly emerged bees exposed to ELF EM fields are the same weight as newly emerged bees not exposed to ELF EM fields.** We hope to be able to add this hypothesis to our next annual report, although data for pre-operational years is limited.

Tables 16 and 17 present mean dry and live weights by sex, year, and site for M. relativa and M. inermis respectively. No statistics have been accomplished with these data. However, the means for M. relativa suggest that there are differences between years for both sexes, with weights reduced during the drought years of 1986 and especially 1988, when hawkweed did not bloom. There may also be differences between sites (eg., bees from CL tend to be smaller than bees from other sites). There do not appear to be systematic differences between experimental and control areas.

After weighing, the bees were pinned and identified. All of the small Megachile bees from 1986 - 1988 nests have been confirmed as M. relativa. The 1989 bees will be pinned and identified after they are weighed.

### Number of cells per nest

Number of cells per complete nest ranged from 1 to 12 for M. relativa. In a CATMOD analysis of cells per nest we used four categories to minimize the cases in which expected frequency was less than five. The categories were: nests with 1 or 2 cells, nests with 3 or 4 cells, nests with 5 or 6 cells, and nests with seven or more cells (Fig. 18).

There were significant differences in the distribution of number of cells per nest between Sites, Years, Exp, and the interaction between Exp and Year (Table 18). Examination of Fig. 18 suggests why these parameters are significant. For example, nests constructed in the drought year of 1988 tend to have fewer cells than nests constructed in 1987; CL and F2 have fewer cells per nest than do C5 and F1. Although Exp\*Yr is significant, it

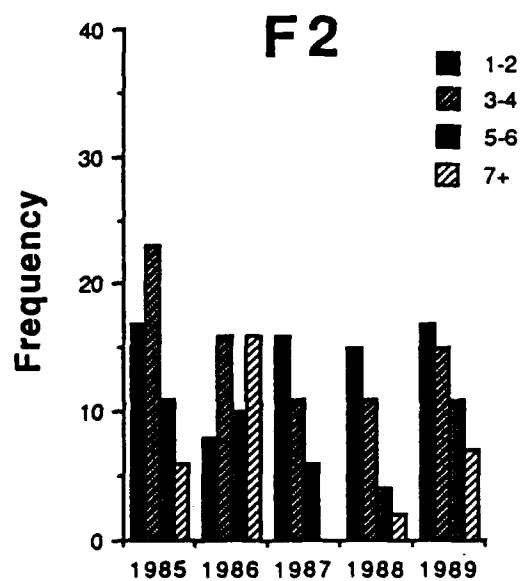
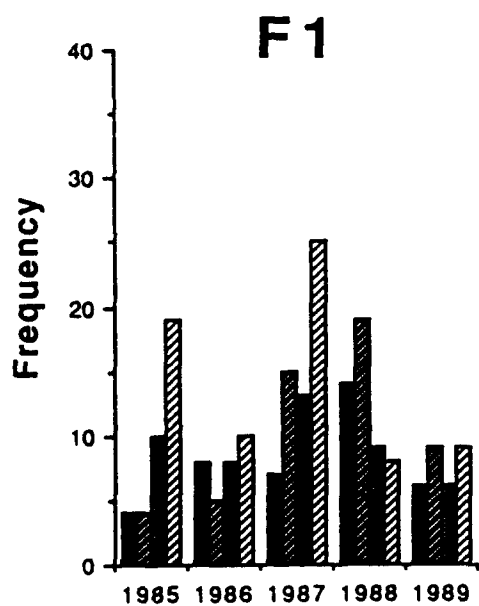
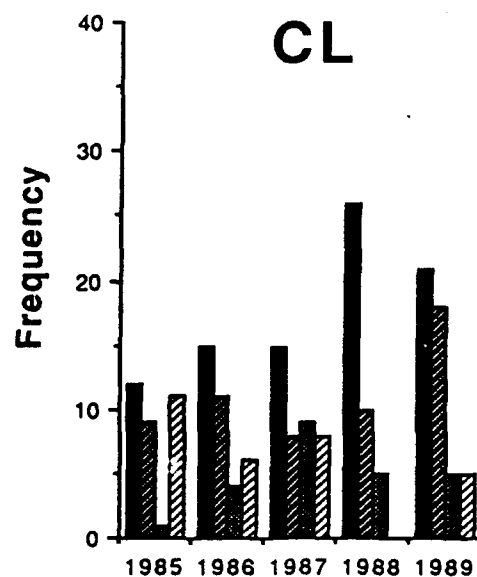
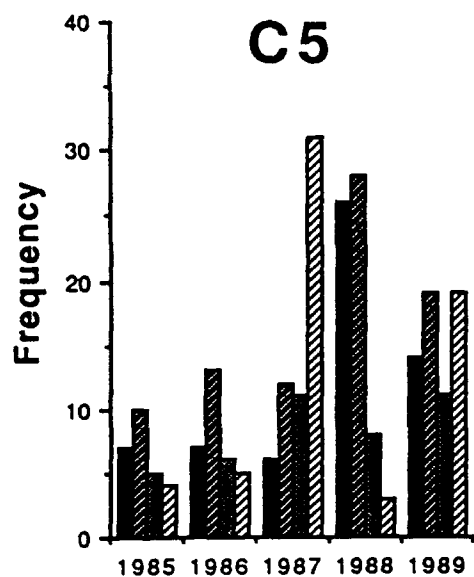


FIGURE 18. Number of complete nests of *M. relativa* with 1-2, 3-4, 5-6 or 7+ cells.

TABLE 18: Categorical modeling of number of cells per complete nest of Megachile relativa, 1985-1989.

NUMBER OF CELLS PER COMPLETE NEST

| Source of variation | df | Chi.Square | Prob.     |
|---------------------|----|------------|-----------|
| Intercept           | 3  | 43.69      | 0.0001*** |
| Exp                 | 3  | 11.23      | 0.0106*   |
| Site[Exp]           | 6  | 59.89      | 0.0001*** |
| Year                | 12 | 46.80      | 0.0001*** |
| Exp*Year            | 12 | 21.58      | 0.0425*   |
| Likelihood Ratio    | 24 | 50.59      | 0.0012*   |

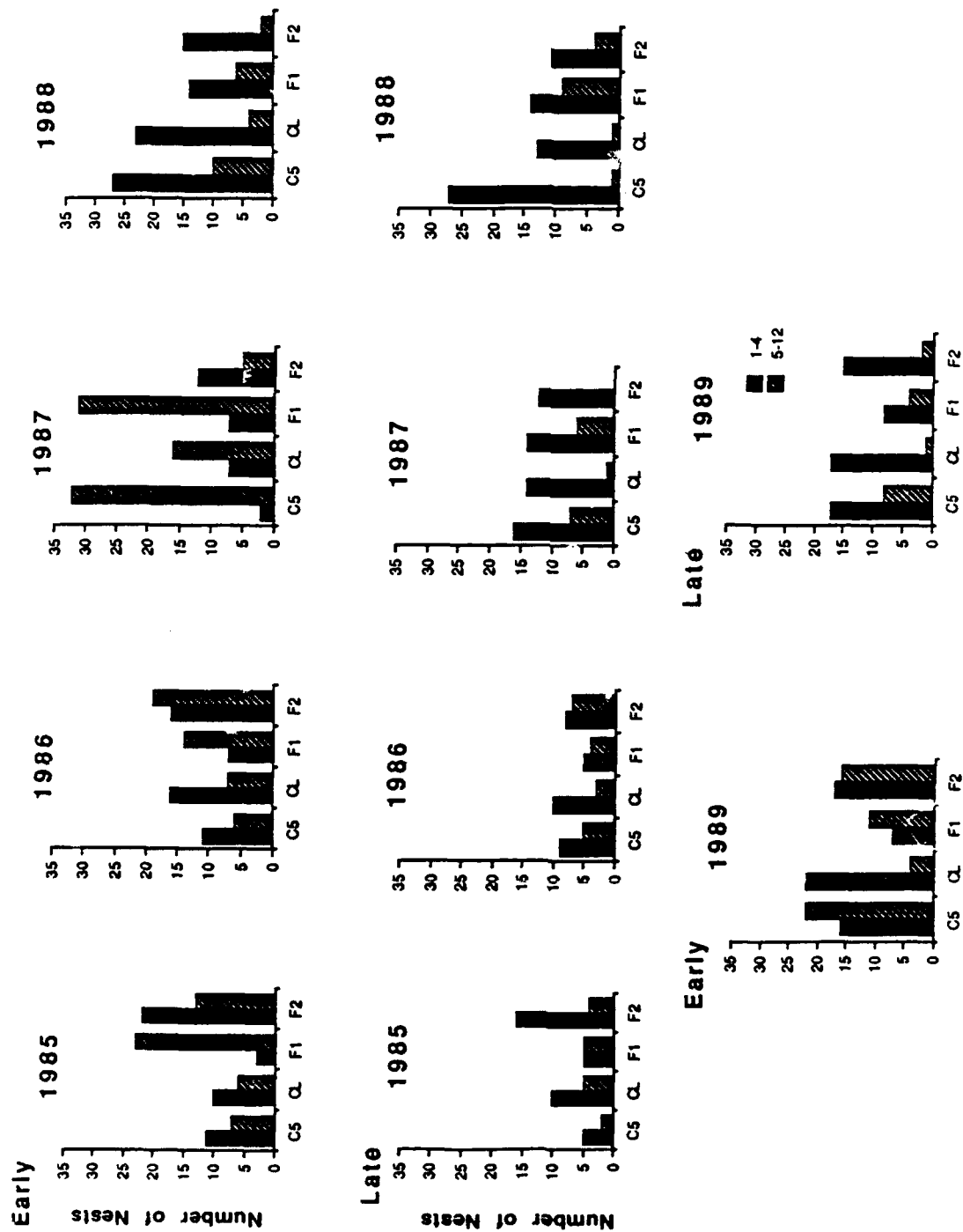


FIGURE 19. Number of complete nests of *M. relativa* with few (1-4) or many (5-12) cells, separated by season.

Table 19. Categorical modeling of number of cells per complete nest of Megachile relativa, 1985-1988.

NUMBER OF CELLS PER COMPLETE NEST

| Source of variation  | df | Chi.Square | Prob.     |
|----------------------|----|------------|-----------|
| Intercept            | 1  | 54.02      | 0.0001*** |
| Exp                  | 1  | 6.58       | 0.0103*   |
| Site[Exp]            | 2  | 42.26      | 0.0001*** |
| Year                 | 4  | 30.40      | 0.0001*** |
| Early vs Late Season | 1  | 41.26      | 0.0001*** |
| Exp*Year             | 4  | 14.36      | 0.0062*   |
| Exp*Season           | 1  | 0.66       | 0.4180    |
| Year*Season          | 4  | 22.44      | 0.0002*** |
| Exp*Year*Season      | 4  | 10.71      | 0.0300*   |
| Likelihood Ratio     | 18 | 24.16      | 0.1206    |



does not appear to be related to effects of ELF EM fields. In 1989 when the ELF antenna was fully operational, cells per nest at experimental sites did not show any obvious change as compared with control sites.

Similar patterns can be observed when early vs. late season nests are also compared in a CATMOD analysis. Two categories of nests were used: 1-4 cells, and 5-12 cells (Fig. 19, Table 19). This analysis indicated that late season nests usually have fewer cells than early season nests. The effect of season on cells per nest was different in different years (Year\*Season interaction is significant - compare 1987 and 1988). In addition, the effects of seasons were different for experimental and control areas in some years (significant Exp\*Year\*Season interaction). In particular, the proportion of large nests increased in late season for the experimental sites in 1988. Because this effect did not continue in 1989, we suggest it may be related to the 1988 drought, not to the ELF antenna.

Number of cells per complete nest ranged from 1 to 8 for M. inermis. The deeper the nest, the more cells can be constructed. Therefore, in analyzing cells per nest for M. inermis, we compare only 1987 - 1989 nests, when bore depth was routinely 140mm and only drill bits of 11mm were used to make large diameter nests. In all years, the experimental sites have more cells per nest than do control sites (Fig. 20), as confirmed by CATMOD analysis (Table 20) using two categories (1-4 cells or 5-7 cells). No significant Exp\*Year interaction indicates no effect of ELF EM fields.

No significant differences between years for M. inermis suggests that, unlike M. relativa, M. inermis did not produce fewer cells per nest in the drought year of 1988. This is surprising, since one might expect lack of resources to affect a large species more than a small species. Apparently these two species responded differently to the drought: The small species produced more nests in 1988 than in previous years (Table 3), but with fewer cells per nest (Fig. 18) especially early season (Fig. 19) and with smaller offspring (Table 16). The large species produced fewer nests in 1988 (Table 3), possibly with smaller offspring (Table 17), but maintained a similar distribution of cells per nest as in 1987, a non-drought year.

Early vs. late season was added to the catmod analysis for M. inermis (Fig. 21, Table 21). In this analysis, nests from 1987 and 1988 were pooled. Season was significant, with more large nests produced early season than late season. Exp was significant, presumably because nests from the experimental sites, F1 and F2, had a greater proportion of large nests than do nests from control sites. Finally, Year\*season was significant, suggesting that late season nests in 1989 had a greater proportion of small nests than did late season nests in 1987-1988. The Exp\*Year\*Season interaction was not significant, indicating that the fully operational ELF EM fields in 1989 did not affect early or late season nests differentially.

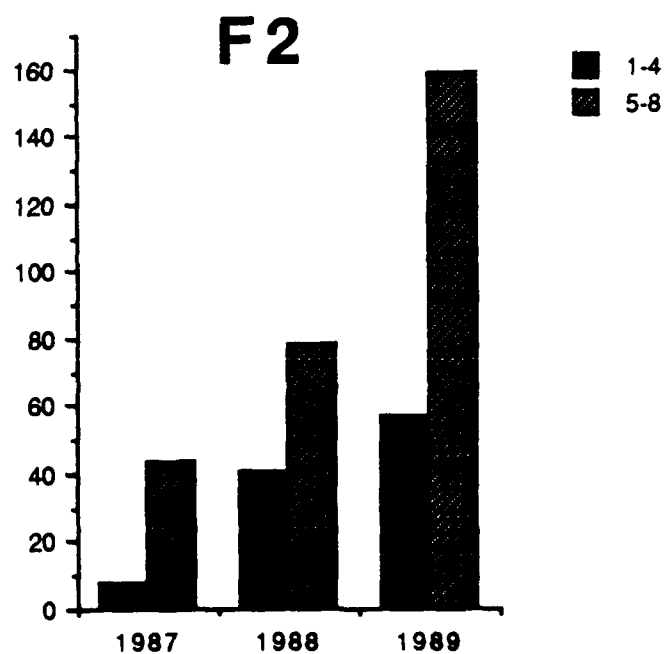
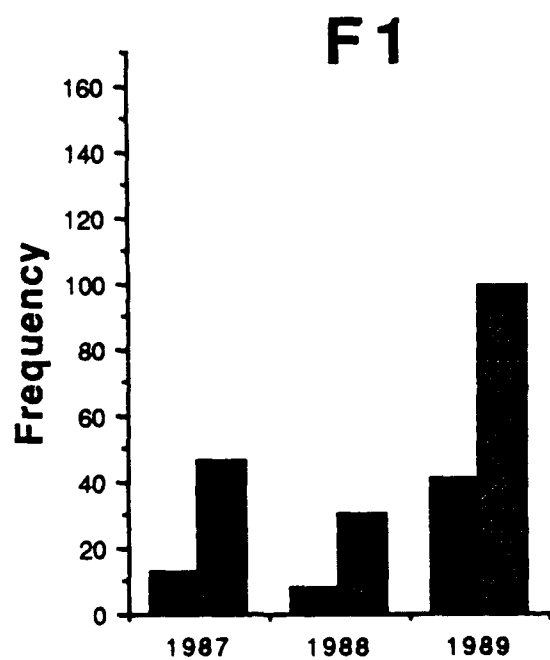
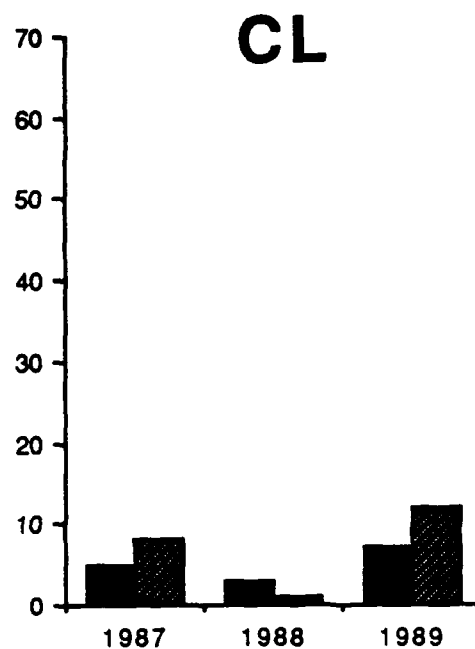
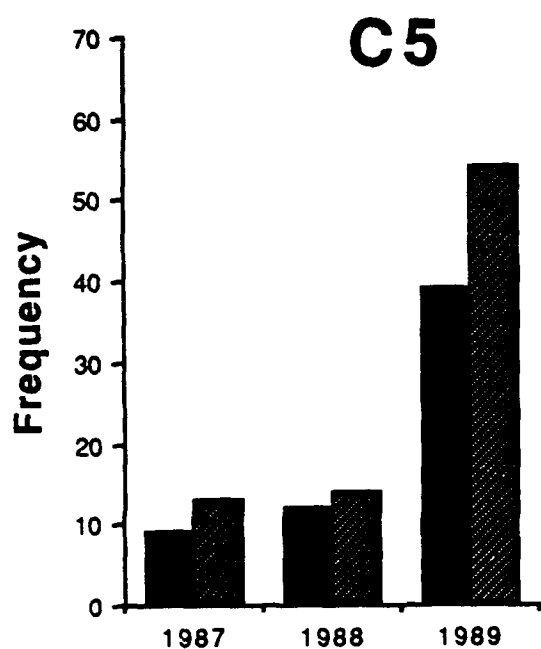


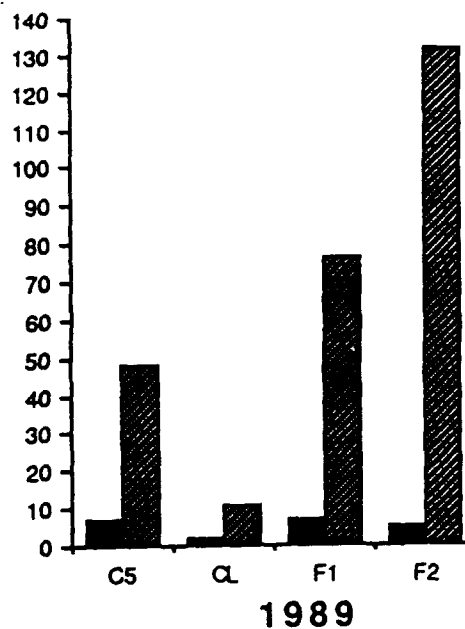
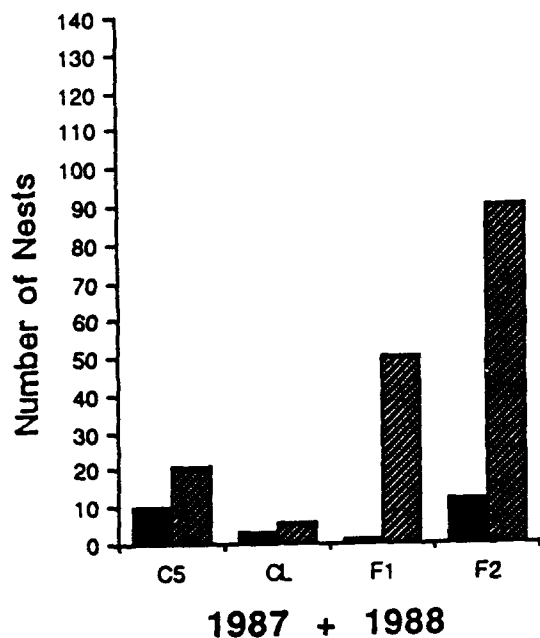
FIGURE 20. Number of complete nests of *M. inermis* with few (1-4) or many (5-8) cells; diameters >9.5, bore depths >135mm.

TABLE 20: Categorical modeling of number of cells per complete nest of Megachile inermis, 1987-1989 (diameters > 9.5mm, bore depths > 135mm).

NUMBER OF CELLS PER COMPLETE NEST

| Source of variation | df | Chi.Square | Prob.     |
|---------------------|----|------------|-----------|
| Intercept           | 1  | 31.72      | 0.0001*** |
| Exp                 | 1  | 11.96      | 0.0005*** |
| Site[Exp]           | 2  | 0.01       | 0.9965    |
| Year                | 2  | 3.29       | 0.1932    |
| Exp*Year            | 2  | 0.88       | 0.6443    |
| Likelihood Ratio    | 4  | 5.08       | 0.2790    |

## Early Season



## Late Season

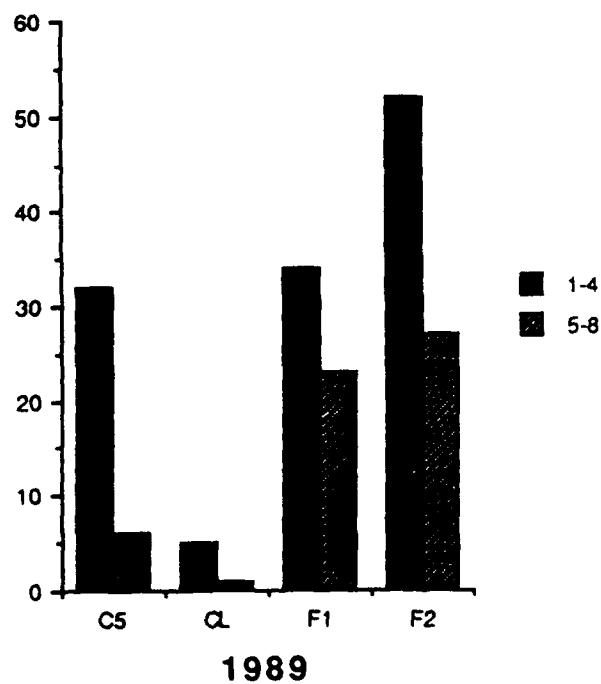
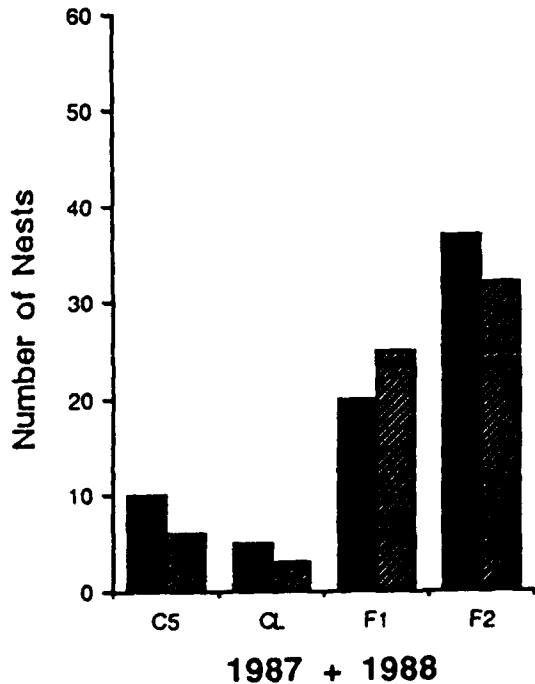


FIGURE 21. Number of complete nests of *M. inermis* with few (1-4) or many (5-8) cells, separated by season; diameters >9.5mm, bore depths >135mm.

TABLE 21: Categorical modeling of number of cells per complete nest of Megachile inermis, 1987 + 1988 vs 1989: (diameters > 9.5mm, bore depths >135mm).

NUMBER OF CELLS PER COMPLETE NEST

| Source of variation   | df | Chi.Square | Prob.     |
|-----------------------|----|------------|-----------|
| Intercept             | 1  | 24.33      | 0.0001*** |
| Exp                   | 1  | 18.02      | 0.0001*** |
| Site[Exp]             | 2  | 1.49       | 0.4745    |
| Year (87+88 vs 89)    | 1  | 0.01       | 0.9074    |
| Early vs. Late Season | 1  | 135.08     | 0.0001*** |
| Exp*Year              | 1  | 0.01       | 0.9419    |
| Exp.*Season           | 1  | 1.28       | 0.2575    |
| Year*Season           | 1  | 13.28      | 0.0003*** |
| Exp.*Year*Season      | 1  | 2.02       | 0.1554    |
| Likelihood Ratio      | 6  | 7.47       | 0.2799    |

**Hypothesis 2. Bees exposed to ELF EM fields, and bees not exposed, will make nest plugs of the same thickness and will devote the same proportion of nest space to reproduction.**

Although the data is available in our INGRES database, we have begun to create a SAS data set consisting of nest plug length, the sum of lengths of all reproductive cells, and the sum of lengths of basal spaces, nest plugs, indentations, and other non-reproductive space for M. inermis. The length of nest plugs will be tested first with M. inermis, since complete nests for this species usually have a solid, uninterrupted nest plug between the last reproductive cell and the nest opening. In contrast, M. relativa nests usually have empty vestibular spaces between two or more nest plugs (Fig. 1), and are thus more complex to analyze. Because nest plug lengths for M. inermis are skewed in distribution (eg., Fig. 22) we will consider categorical modeling of different length classes (eg. 5-20mm, 20-35mm, 35-50mm, >50mm). Somehow, we must take into account the number of reproductive cells in the nest, since the space left over for plug decreases as the number of cells increase, and the variance in plug length decreases as the number of cells increase.

In analyzing the proportion of space devoted to reproduction, we wish to compare the sum of reproductive cell lengths with total space in the nest used by the bee. The ratio of reproductive space to used space approaches 1.0 as the length of nest plugs and vestibular spaces decreases. We can test whether the distributions of this ratio for experimental and control areas are the same, using a Goodness of fit test.

**Hypothesis 3. The number of leaves used to line a cell is unchanged when bees are exposed to ELF EM fields.**

As with cell lengths, a mean of ln leaves per cell was calculated for each nest and used in GLM analysis. In some years, numbers of nests are very low at some sites (eg., 1 nest at the CL site in 1986, 1988). Therefore, data on leaves per cell were pooled for pre-operational years (1985-1987 or 1985-1988) and operational years (1988-1989 or 1989). Only nests with diameters greater than 9.5mm were used in the analysis. When all cells are analyzed the residuals are significantly different from normal ( $P < 0.01$ ). When cells with male and female offspring are analyzed separately, the residuals are not significantly different from normal ( $P > .15$ ) except for 1989 male cells ( $P < 0.01$ ). Although the number of leaves lining a cell is discrete data, treating it as if it were continuous, and using the GLM procedure on the mean ln of leaves per cell, instead of a CATMOD analysis, should increase our ability to detect differences between control and experimental areas.

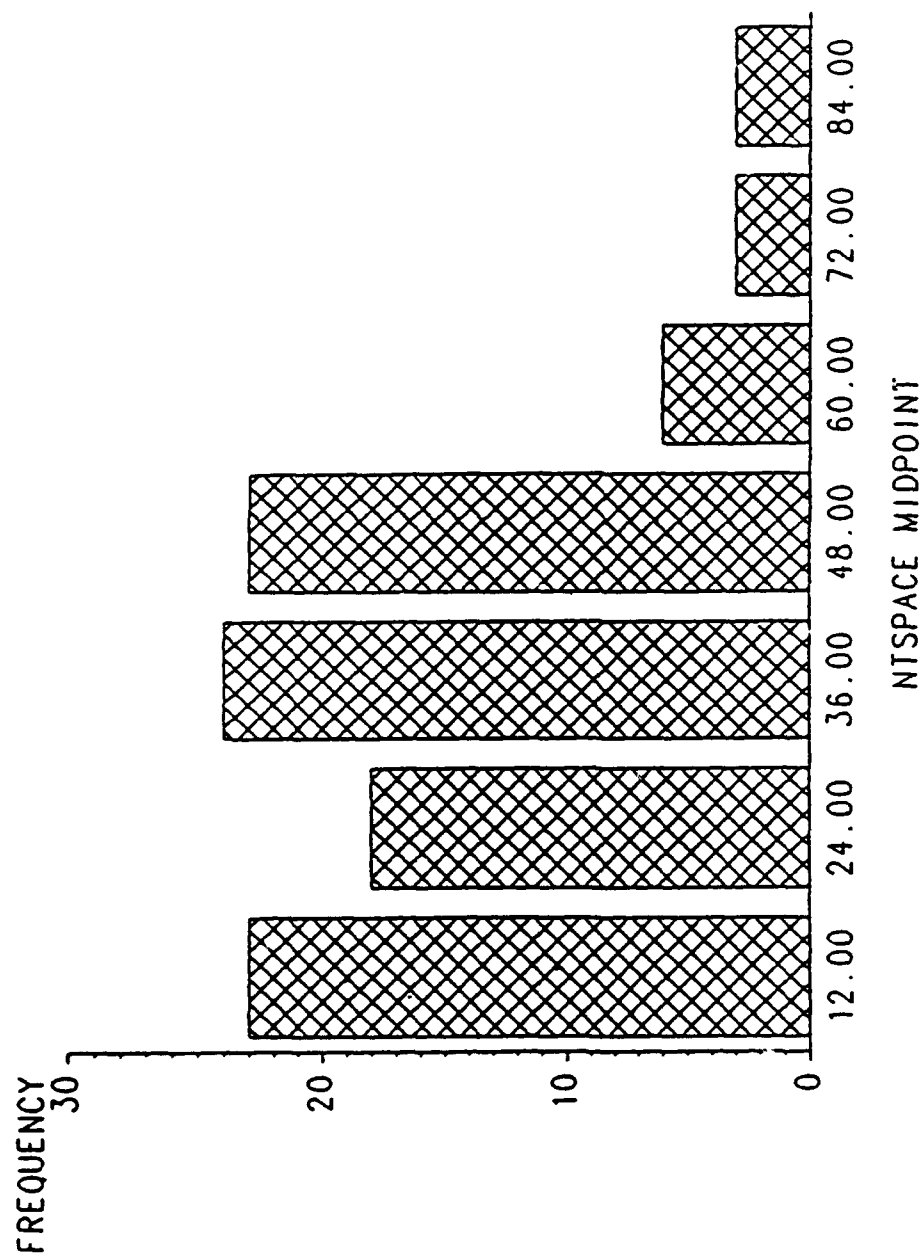


FIGURE 22. Distribution of nest plug lengths for *M. inermis*, 1985 nests.

If ELF EM fields were having an effect on leaves per cell, we would expect to see mean leaves per cell changing for the treatment sites but not for the control sites in operational years. This does not seem to be the case. Mean of ln leaves per cell for experimental sites overlapped with means for control sites, and actual differences were less than differences necessary to detect significance (Fig. 23). There was no significant effect of Exp, or Exp \* year in any of the models (Table 22, 23). This suggests that ELF EM fields during the summers of 1988 and 1989 did not have any effect on the number of leaves per M. inermis cell. Furthermore, there are no intrinsic differences between experimental and control areas contributing to variability in leaves per cell. Therefore, there does not yet appear to be any influence of ELF EM fields on leaves per cell for this species. However, it is possible that differences in mean ln leaves per cell will be detected in future years when bees are exposed to continuous full power EM fields.

Male cells were constructed with more leaves (12.1) than female cells (10.7) on average (Tables 22, 23). Coefficients of variation in the tests ranged from 6.9-7.1%, and 18% (females) - 25% (males) of the variability was explained by the models. Between nest variability (error ms) is large. Early season nests were constructed with fewer leaves per cell for both male and female cells. Male cells in complete nests were constructed with fewer leaves than in incomplete cells. Male cells at the CL site tended to be constructed with fewer leaves, and cells at the F1 site with more leaves than cells from C5 or F2.

**Hypothesis 4. The relative acceptability of nests oriented in a NS direction vs. nests oriented in an EW direction does not change when bees are exposed to ELF EM fields.**

As explained in the methods section, at each site there are three sets of hutches. Each hutch set consists of two hutches in close proximity, one oriented N-S, and one oriented E-W. Nests on the N-S hutch have openings facing E or W, while nests on the E-W hutch have openings facing N or S. The directions used in this analysis refer to the direction of nest openings.

Each set of hutches is situated in a different location and has a different pattern of sun and shade during the day, and a different compliment of nearby flowering plants. These factors may be important in acceptance of nest opening direction by bees. Thus, we have analyzed nest orientation by hutch set at each site. Furthermore, since sample sizes are low at some hutches in some years, we have not tried to discriminate between nests oriented in four directions; rather we compare acceptance of nests oriented



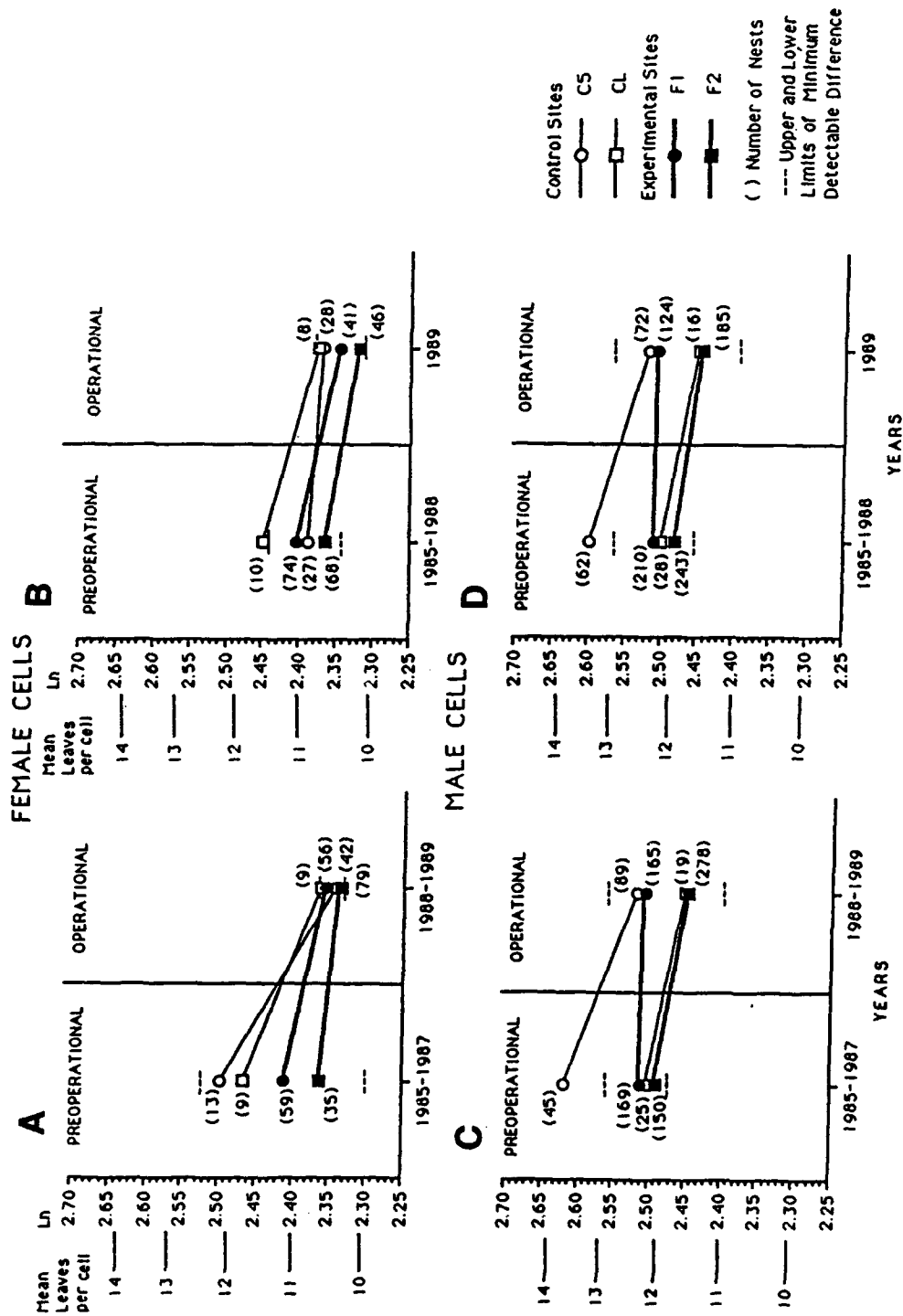


FIGURE 23. Mean leaves per cell for *M. inermis* nests, diameters 9.5mm. A: Cells expected to be female; 1985-1987 vs. 1988-1989. B: Cells expected to be female; 1985-1988 vs. 1989. C: Cells expected to be male; 1985-1987 vs. 1988-1989. D: Cells expected to be male; 1985-1988 vs. 1989. Numbers of nests in parenthesis; Horizontal dashes indicate the upper and lower limits to the minimum detectable difference between experimental and control area for each year.

TABLE 22a: GLM of mean of ln transformed leaves per cell in *M. inermis* nests. Cells expected to have female offspring; pooled pre-operational vs operational yrs; diameters >9.5mm.

LEAVES PER CELL

| Source of variation                                     | df  | SS   | F     | P>F       |
|---|-----|------|-------|-----------|
| Year (85-87 vs 88-89)                                   | 1   | 0.02 | 0.78  | 0.3791    |
| Diameter  | 1   | 0.02 | 0.77  | 0.3804    |
| Exp   | 1   | 0.13 | 4.06  | 0.1815    |
| Site[Exp]   | 2   | 0.07 | 1.23  | 0.2927    |
| Exp*Year  | 1   | 0.09 | 2.72  | 0.2406    |
| Complete vs. incomplete                                 | 1   | 0.01 | 0.48  | 0.4898    |
| Cells per nest  | 1   | 0.00 | 0.01  | 0.9397    |
| Early vs. Late Season                                   | 1   | 0.34 | 12.89 | 0.0004*** |
| Diameter*Year   | 1   | 0.02 | 0.73  | 0.3939    |
| Bore depth  | 1   | 0.18 | 0.69  | 0.4069    |
| Bore depth*Year   | 1   | 0.02 | 0.84  | 0.3597    |
| Diameter*Bore depth                                     | 1   | 0.02 | 0.68  | 0.4094    |
| Diameter*Year*<br>Bore depth                            | 1   | 0.02 | 0.79  | 0.3741    |
| Model   | 14  | 1.78 | 4.75  | 0.0001*** |
| Error   | 287 | 7.67 |       |           |
| $\bar{X} = 2.37$ (10.7 leaves)    CV = 6.9 $r^2 = 0.19$ |     |      |       |           |

| Parameter                       | Estimate      | T for $H_0$ :<br>Parameter = 0 | PR >  T         |
|---------------------------------|---------------|--------------------------------|-----------------|
| Early Season vs.<br>Late Season | -0.092<br>0.0 | -3.59<br>--                    | 0.0004***<br>-- |

TABLE 22b: GLM of mean of ln transformed leaves per cell in M. inermis nests. Cells expected to have female offspring; pooled pre-operational vs operational yrs; diameters >9.5mm.

LEAVES PER CELL

| Source of variation            | df       | SS           | F     | P>F       |
|--------------------------------|----------|--------------|-------|-----------|
| Year (85-88 vs 89)             | 1        | 0.02         | 0.90  | 0.3437    |
| Diameter                       | 1        | 0.03         | 1.05  | 0.3056    |
| Exp                            | 1        | 0.11         | 4.24  | 0.1755    |
| Site[Exp]                      | 2        | 0.05         | 0.96  | 0.3842    |
| Exp*Year                       | 1        | 0.00         | 0.03  | 0.8698    |
| Complete vs.<br>incomplete     | 1        | 0.00         | 0.17  | 0.6793    |
| Cells per nest                 | 1        | 0.00         | 0.04  | 0.8456    |
| Early vs. Late Season          | 1        | 0.35         | 13.13 | 0.0003*** |
| Diameter*Year                  | 1        | 0.02         | 0.82  | 0.3659    |
| Bore depth                     | 1        | 0.03         | 1.09  | 0.2966    |
| Bore depth*Year                | 1        | 0.02         | 0.91  | 0.3405    |
| Diameter*Bore depth            | 1        | 0.03         | 1.02  | 0.3135    |
| Diameter*Year*<br>Bore depth   | 1        | 0.02         | 0.83  | 0.3625    |
| Model                          | 14       | 1.70         | 4.49  | 0.0001*** |
| Error                          | 287      | 7.75         |       |           |
| $\bar{X} = 2.37$ (10.7 leaves) | CV = 6.9 | $r^2 = 0.18$ |       |           |

| Parameter                       | Estimate      | T for $H_0$ :<br>Parameter = 0 | PR >  T         |
|---------------------------------|---------------|--------------------------------|-----------------|
| Early Season vs.<br>Late Season | -0.088<br>0.0 | -3.62<br>--                    | 0.0003***<br>-- |

TABLE 23a: GLM of mean of ln transformed leaves per cell in M. inermis nests. Cells expected to have male offspring; pooled pre-operational vs operational yrs; diameters >9.5mm.

LEAVES PER CELL

| Source of variation            | df       | SS           | F     | P>F       |
|--------------------------------|----------|--------------|-------|-----------|
| Year (85-87 vs 88-89)          | 1        | 0.01         | 0.32  | 0.5718    |
| Diameter                       | 1        | 0.06         | 1.90  | 0.1679    |
| Exp                            | 1        | 0.31         | 1.98  | 0.2946    |
| Site[Exp]                      | 2        | 0.31         | 5.12  | 0.0062*   |
| Exp*Year                       | 1        | 0.10         | 0.66  | 0.5016    |
| Complete vs. incomplete        | 1        | 0.22         | 7.13  | 0.0077*   |
| Cells per nest                 | 1        | 0.06         | 2.01  | 0.1566    |
| Early vs. Late Season          | 1        | 2.30         | 74.99 | 0.0001*** |
| Diameter*Year                  | 1        | 0.01         | 0.27  | 0.6035    |
| Bore depth                     | 1        | 0.06         | 1.80  | 0.1797    |
| Bore depth*Year                | 1        | 0.01         | 0.35  | 0.5518    |
| Diameter*Bore depth            | 1        | 0.06         | 1.80  | 0.1799    |
| Diameter*Year*<br>Bore depth   | 1        | 0.01         | 0.30  | 0.5846    |
| Model                          | 14       | 9.51         | 22.12 | 0.0 ***   |
| Error                          | 925      | 28.41        |       |           |
| <hr/>                          |          |              |       |           |
| $\bar{X} = 2.49$ (12.1 leaves) | CV = 7.0 | $r^2 = 0.25$ |       |           |

Table 23a continued:

| Parameter                       | Estimate       | T for $H_0$ :<br>Parameter = 0 | PR >  T         |
|---------------------------------|----------------|--------------------------------|-----------------|
| Site[Exp] C5                    | 0.0            | --                             | --              |
| CL                              | -0.0665        | -2.12                          | 0.0313*         |
| F1                              | 0.0317         | 2.42                           | 0.0131*         |
| F2                              | 0.0            | --                             | --              |
| Complete vs.<br>Incomplete      | 0.0532<br>0.0  | -2.67<br>--                    | 0.0077*<br>--   |
| Early Season vs.<br>Late Season | -0.1176<br>0.0 | -8.66<br>--                    | 0.0001***<br>-- |

TABLE 23b: GLM of mean of  $\ln$  transformed leaves per cell in M. inermis nests. Cells expected to have male offspring; pooled pre-operational vs operational yrs; diameters >9.5mm.

LEAVES PER CELL

| Source of variation            | df       | SS           | F     | P>F       |
|--------------------------------|----------|--------------|-------|-----------|
| Year (85-88 vs 89)             | 1        | 0.01         | 0.27  | 0.6026    |
| Diameter                       | 1        | 0.04         | 1.21  | 0.2722    |
| Exp                            | 1        | 0.18         | 1.13  | 0.3995    |
| Site[Exp]                      | 2        | 0.31         | 5.02  | 0.0068*   |
| Exp*Year                       | 1        | 0.11         | 0.67  | 0.4990    |
| Complete vs.<br>incomplete     | 1        | 0.19         | 5.99  | 0.0145*   |
| Cells per nest                 | 1        | 0.00         | 0.13  | 0.7229    |
| Early vs. Late Season          | 1        | 1.99         | 63.43 | 0.0001*** |
| Diameter*Year                  | 1        | 0.01         | 0.26  | 0.6087    |
| Bore depth                     | 1        | 0.04         | 1.14  | 0.2860    |
| Bore depth*Year                | 1        | 0.01         | 0.27  | 0.6024    |
| Diameter*Bore depth            | 1        | 0.04         | 1.15  | 0.2831    |
| Diameter*Year*<br>Bore depth   | 1        | 0.01         | 0.26  | 0.6086    |
| Model                          | 14       | 8.93         | 20.34 | 0.0 ***   |
| Error                          | 925      | 29.00        |       |           |
| $\bar{X} = 2.49$ (12.1 leaves) | CV = 7.1 | $r^2 = 0.24$ |       |           |

Table 23b (continued)

| Parameter                       | Estimate       | T for $H_0$ :<br>Parameter = 0 | PR >  T         |
|---------------------------------|----------------|--------------------------------|-----------------|
| Site[Exp] C5                    | 0.0            | --                             | --              |
| CL                              | -0.0712        | -2.27                          | 0.0234*         |
| F1                              | 0.0292         | 2.22                           | 0.0264*         |
| F2                              | 0.0            | --                             | --              |
| Complete vs.<br>Incomplete      | -0.0492<br>0.0 | -2.45<br>--                    | 0.0145**<br>--  |
| Early Season vs.<br>Late Season | -0.1070<br>0.0 | -7.96<br>--                    | 0.0001***<br>-- |

TABLE 24: CHI-SQUARE HETEROGENEITY GOODNESS OF FIT ANALYSIS

H<sub>0</sub>: Nest orientations at each hutch set are homogeneous between years in a 50% E-W, 50% N-S distribution, so that data for a hutch set can be pooled across years.

| EW NS Total $\chi^2$ df                   |    |    |     |              |               | EW NS Total $\chi^2$ df |    |    |       |               |  |
|---|----|----|-----|--------------|---------------|-------------------------|----|----|-------|---------------|--|
| C5-S <sup>1</sup>                         |    |    |     |              |               | CL-E <sup>1</sup>       |    |    |       |               |  |
| 1985                                      | 6  | 5  | 11  | 0.091        | 1 n.s.        | 15                      | 9  | 24 | 1.500 | 1 n.s.        |  |
| 1986                                      | 4  | 6  | 10  | 0.400        | 1 n.s.        | 8                       | 3  | 11 | 2.273 | 1 n.s.        |  |
| 1987                                      | 6  | 16 | 22  | 4.545        | 1 .025 <P<.05 | 12                      | 6  | 18 | 2.000 | 1 n.s.        |  |
| 1988                                      | 4  | 19 | 23  | 9.783        | 1 .001<P<.005 | 13                      | 2  | 15 | 8.067 | 1 .001<P<.005 |  |
| 1989                                      | 9  | 12 | 21  | 0.429        | 1 n.s.        | 12                      | 7  | 19 | 1.316 | 1 n.s.        |  |
| C5-N <sup>3</sup>                         |    |    |     |              |               | CL-N <sup>1</sup>       |    |    |       |               |  |
| 1985                                      | 4  | 2  | 6   | —            |               | 12                      | 7  | 19 | 1.316 | 1 n.s.        |  |
| 1986                                      | 5  | 6  | 11  | 0.091        | 1 n.s.        | 10                      | 7  | 17 | 0.529 | 1 n.s.        |  |
| 1987                                      | 4  | 3  | 7   | —            |               | 10                      | 3  | 13 | 3.769 | 1 n.s.        |  |
| 1988                                      | 12 | 3  | 15  | 5.400        | 1 .01<P<.025  | 17                      | 4  | 21 | 8.048 | 1 .001<P<.005 |  |
| 1989*                                     | 9  | 13 | 22  | 0.727        | 1 n.s.        | 11                      | 1  | 12 | 8.333 | 1 .001<P<.005 |  |
| C5-W <sup>2</sup>                         |    |    |     |              |               | CL-W <sup>3</sup>       |    |    |       |               |  |
| 1985                                      | 8  | 14 | 22  | 1.636        | 1 n.s.        | 7                       | 4  | 11 | 0.818 | 1 n.s.        |  |
| 1986                                      | 11 | 7  | 18  | 0.889        | 1 n.s.        | 6                       | 8  | 14 | 0.286 | 1 n.s.        |  |
| 1987                                      | 18 | 18 | 36  | 0.000        | 1 n.s.        | 5                       | 6  | 11 | 0.091 | 1 n.s.        |  |
| 1988                                      | 14 | 24 | 38  | 2.632        | 1 n.s.        | 3                       | 6  | 9  | —     |               |  |
| 1989                                      | 14 | 10 | 24  | 0.667        | 1 n.s.        | 9                       | 11 | 20 | 0.200 | 1 n.s.        |  |
| C5-W                                      |    |    |     |              |               |                         |    |    |       |               |  |
| Totals                                    | 65 | 73 | 138 | 1.263        | 1 n.s.        |                         |    |    |       |               |  |
| Total of $\chi^2$ s                       |    |    |     | 5.824        | 5             |                         |    |    |       |               |  |
| $\chi^2$ s of totals                      |    |    |     | <u>0.464</u> | 1             |                         |    |    |       |               |  |
|   |    |    |     | 5.360        | 4 n.s.        |                         |    |    |       |               |  |
| $\chi^2$ of totals with Yates correction: |    |    |     | 0.355        | 1 n.s.        |                         |    |    |       |               |  |

<sup>1</sup> Data for these hutch sets are heterogeneous between years.

<sup>2</sup> Data for this hutch sets is homogeneous across years. The Yates correction is not applied until the final heterogeneity  $\chi^2$  (Zar, 1974, p. 51).

<sup>3</sup> Sample sizes are too small to apply a Chi-Square test to data for some years, so heterogeneity test can't be made.



# OF M. RELATIVA NEST ORIENTATION BY HUTCH SET AND YEAR

H<sub>1</sub>: Nest orientations at each hutch set are not in a 50% E-W, 50% N-S distribution and/or are heterogeneous, so data cannot be pooled across years.\*

| EW                | NS        | Total | $\chi^2$ | df |            | EW                | NS        | Total | $\chi^2$ | df |            |
|-------------------|-----------|-------|----------|----|------------|-------------------|-----------|-------|----------|----|------------|
| F1-E <sup>1</sup> |           |       |          |    |            | F2-E <sup>1</sup> |           |       |          |    |            |
| 15                | <b>6</b>  | 21    | 3.857    | 1  | .025<P<.05 | 9                 | <b>5</b>  | 14    | 1.143    | 1  | n.s.       |
| 12                | <b>4</b>  | 16    | 4.000    | 1  | .025<P<.05 | 10                | <b>16</b> | 26    | 1.385    | 1  | n.s.       |
| 18                | <b>21</b> | 39    | 0.231    | 1  | n.s.       | 6                 | <b>9</b>  | 15    | 0.600    | 1  | n.s.       |
| 7                 | <b>9</b>  | 16    | 0.250    | 1  | n.s.       | 4                 | <b>16</b> | 20    | 7.200    | 1  | .005<P<.01 |
| 5                 | <b>6</b>  | 11    | 0.091    | 1  | n.s.       | 10                | <b>12</b> | 22    | 0.182    | 1  | n.s.       |
| F1-N <sup>1</sup> |           |       |          |    |            | F2-N <sup>1</sup> |           |       |          |    |            |
| 15                | <b>5</b>  | 20    | 5.000    | 1  | n.s.       | 20                | <b>17</b> | 37    | 0.243    | 1  | n.s.       |
| 5                 | <b>8</b>  | 13    | 1.646    | 1  | n.s.       | 10                | <b>23</b> | 33    | 5.313    | 1  | .01<P<.025 |
| 6                 | <b>16</b> | 22    | 4.545    | 1  | .025<P<.05 | 7                 | <b>10</b> | 17    | 0.529    | 1  | n.s.       |
| 4                 | <b>22</b> | 26    | 12.462   | 1  | P<.001     | 5                 | <b>8</b>  | 13    | 0.692    | 1  | n.s.       |
| 2                 | <b>16</b> | 18    | 10.889   | 1  | P<.001     | 8                 | <b>19</b> | 27    | 4.481    | 1  | .025<P<.05 |
| F1-W <sup>3</sup> |           |       |          |    |            | F2-W <sup>3</sup> |           |       |          |    |            |
| 2                 | <b>12</b> | 14    | 7.143    | 1  | .01<P<.005 | 8                 | <b>10</b> | 18    | 0.222    | 1  | n.s.       |
| 4                 | <b>2</b>  | 6     | —        |    |            | 5                 | <b>1</b>  | 6     | —        |    |            |
| 2                 | <b>2</b>  | 4     | —        |    |            | 2                 | <b>4</b>  | 6     | —        |    |            |
| 10                | <b>5</b>  | 15    | 1.667    | 1  | n.s.       | 3                 | <b>3</b>  | 6     | —        |    |            |
| 2                 | <b>2</b>  | 4     | —        |    |            | 3                 | <b>4</b>  | 7     | —        |    |            |

\* #'s in bold indicate a directional preference.

TABLE 25: LOG-LIKELIHOOD RATIO HETEROGENEITY CONTINGENCY HUTCH SET AND YEAR

$H_0$ : Nest orientations at each hutch set are homogeneous between years (i.e., have the same directional preference).

|                    | EW  | NS  | R   |  | EW                 | NS  | R  |                         |  |
|--------------------|-----|-----|-----|--|--------------------|-----|----|-------------------------|--|
| C5-S               |     |     |     |  | CL-E               |     |    |                         |  |
| 1985               | 6   | 5   | 14  | G=6.417<br>df = 4<br>n.s.                  | 15                 | 9   | 24 | G=3.423<br>df=4<br>n.s. |  |
| 1986               | 4   | 6   | 10  |  | 8                  | 3   | 11 |                         |  |
| 1987               | 6   | 16  | 22  |  | 12                 | 6   | 18 |                         |  |
| 1988               | 4   | 19  | 23  |  | 13                 | 2   | 15 |                         |  |
| 1989               | 9   | 12  | 24  |  | 12                 | 7   | 19 |                         |  |
| C                  | 29  | 58  | 87  |  | 60                 | 27  | 87 |                         |  |
| C5-N               |     |     |     |  | CL-N               |     |    |                         |  |
| 1985               | 4   | 2   | 6   | G=6.623<br>df=4<br>n.s.                    | 12                 | 7   | 19 | G=5.952<br>df=4<br>n.s. |  |
| 1986               | 5   | 6   | 11  |  | 10                 | 7   | 17 |                         |  |
| 1987               | 4   | 3   | 7   |  | 10                 | 3   | 13 |                         |  |
| 1988               | 12  | 3   | 15  |  | 17                 | 4   | 21 |                         |  |
| 1989               | 9   | 13  | 22  |  | 11                 | 1   | 12 |                         |  |
| C                  | 34  | 27  | 61  |  | 60                 | 22  | 82 |                         |  |
| C5-W               |     |     |     |  | CL-W               |     |    |                         |  |
| 1985               | 8   | 14  | 22  | G=5.422<br>df=4<br>n.s.                    | 7                  | 4   | 11 | G=2.041<br>df=4<br>n.s. |  |
| 1986               | 11  | 7   | 18  |  | 6                  | 8   | 14 |                         |  |
| 1987               | 18  | 18  | 36  |  | 5                  | 6   | 11 |                         |  |
| 1988               | 14  | 24  | 38  |  | 3                  | 6   | 9  |                         |  |
| 1989               | 14  | 10  | 24  |  | 9                  | 11  | 20 |                         |  |
| C                  | 65  | 73  | 138 |  | 30                 | 35  | 65 |                         |  |
| C5 - BY HUTCH SETS |     |     |     |  | CL - BY HUTCH SETS |     |    |                         |  |
| C5-S               | 29  | 58  | 87  | G=7.971 <sup>1</sup><br>df=2<br>.01<P<.025 | CL-E               | 60  | 27 | 87                      | G=12.652 <sup>1</sup><br>df=2<br>.001<P<.005 |
| C5-N               | 34  | 27  | 61  |  | CL-N               | 60  | 22 | 82                      |  |
| C5-W               | 65  | 73  | 138 |  | CL-W               | 30  | 35 | 65                      |  |
| C                  | 128 | 158 | 286 |  |                    | 150 | 84 | 234                     |  |

1. Within hutch sets, data are homogeneous between years. However, hutch sets (data pooled across years) are heterogeneous. Thus, hutch set data cannot be pooled by year.
2. Within hutch sets data are heterogeneous; cannot be pooled.
3. Data is homogeneous within hutch sets across years and between hutch sets, with a preference toward N-S nest entrances.

# TABLES FOR M. RELATIVA NEST ENTRANCE ORIENTATION BY

H<sub>1</sub>: Nest orientations at each hutch set are heterogeneous between years and hutch sets at a site, so data cannot be pooled.

| EW    | NS  | R   |   | EW   | NS | R   |                         |  |
|-------|-----|-----|---|------|----|-----|-------------------------|--|
| F1-E  |     |     |   | F2-E |    |     |                         |  |
| 15    | 6   | 21  | G=7.567 <sup>2</sup><br>df=4<br>n.s.        | 9    | 5  | 14  | G=7.306<br>df=4<br>n.s. |  |
| 12    | 4   | 16  |   | 10   | 16 | 26  |                         |  |
| 18    | 21  | 39  |   | 6    | 9  | 15  |                         |  |
| 7     | 9   | 16  |   | 4    | 16 | 20  |                         |  |
| 5     | 6   | 11  |   | 10   | 12 | 22  |                         |  |
| 57    | 46  | 103 |   | 39   | 58 | 97  |                         |  |
| F1-N  |     |     |   | F2-N |    |     |                         |  |
| 15    | 5   | 20  | G=24.117 <sup>2</sup><br>df=4<br>P<.001     | 20   | 17 | 37  | G=5.567<br>df=4<br>n.s. |  |
| 5     | 8   | 13  |   | 10   | 23 | 33  |                         |  |
| 6     | 16  | 22  |   | 7    | 10 | 17  |                         |  |
| 4     | 22  | 26  |   | 5    | 8  | 13  |                         |  |
| 2     | 16  | 18  |   | 8    | 19 | 27  |                         |  |
| 32    | 67  | 99  |   | 50   | 77 | 127 |                         |  |
| F1-W  |     |     |   | F2-W |    |     |                         |  |
| 2     | 12  | 14  | G=10.094 <sup>2</sup><br>df=4<br>0.25<P<.05 | 8    | 10 | 18  | G=3.933<br>df=4<br>n.s. |  |
| 4     | 2   | 6   |   | 5    | 1  | 6   |                         |  |
| 2     | 2   | 4   |   | 2    | 4  | 6   |                         |  |
| 10    | 5   | 15  |   | 3    | 3  | 6   |                         |  |
| 2     | 2   | 4   |   | 3    | 4  | 7   |                         |  |
| 20    | 23  | 43  |   | 21   | 22 | 43  |                         |  |
|       |     |     | Total of G tests                            |      |    |     | G=16.806<br>df=12       |  |
|       |     |     | F2 BY HUTCH SET                             |      |    |     |                         |  |
| F2- E | 39  | 58  | 97  |      |    |     | G=1.237 <sup>3</sup>    |  |
| F-2 N | 50  | 77  | 127   |      |    |     | df=2                    |  |
| F2- W | 21  | 22  | 43  |      |    |     | n.s.                    |  |
|       | 110 | 157 | 267   |      |    |     |                         |  |
|       |     |     | Total of G tests                            |      |    |     | 16.806                  |  |
|       |     |     | G-test of totals                            |      |    |     | - 1.237                 |  |
|       |     |     | Heterogeneity G                             |      |    |     | 15.569 <sup>3</sup>     |  |
|       |     |     | df = 12 - 2 = 10                            |      |    |     | n.s.                    |  |

N or S vs. nests oriented E or W. Only data for M. relativa are analyzed, since sample size was very low most years for M. inermis at the control sites.

First we test whether both directions are equally acceptable using a Heterogeneity Chi-Square Goodness of Fit test (Table 24), with expected proportions of 50% N or S and 50% E or W. This test could not be used for years where fewer than 10 nests were constructed for a hutch set, because the expected frequencies would be less than 5. In cases where the test could be applied, the data were heterogeneous (except for the C5 W hutch). This means that in some years acceptance of nest directions was not different from a 50-50 distribution, while in other years the nests were different from 50-50 at a given hutch set.

As an alternative approach, we analyzed the same data with Log-likelihood Ratio (G-test) Heterogeneity Contingency test (Table 25). This tests whether the pattern of nest acceptability (whatever the pattern) is the same for all years at a given hutch set. When the null hypothesis was accepted for all hutch sets at a site, the data were pooled over hutch sets, and each hutch set was tested against the other hutch sets at that site, to test whether the pattern was consistent for the entire site.

The results indicate that there is often a consistent bias over the years at a given hutch set, but that often the bias is different between hutch sets. These biases are probably due to differences in shading and proximity to resources, which are fairly consistent between years. If ELF EM fields are beginning to affect nest orientation acceptability, one might expect changes in nest orientation within a hutch set over the years at experimental but not control areas. Only two hutch sets at the F1 site have shown significant changes within a hutch set over the years. These differences appear to be due to differences between 1985 and subsequent years. If a G-test was repeated with 1985 data removed, the F1-N hutch has a consistent bias toward the NS direction ( $G=4.291$ ,  $df = 3$  n.s.) while the F1-W hutch has a bias toward the EW direction ( $G=0.672$ ,  $df = 3$  n.s.). We have no idea why nest directions were different in 1985 than in other years at the F1 site, but this change cannot be related to ELF EM fields.

We will be interested to see if there are any changes in the preferred hutch directions at the experimental sites for the 1990 nests, the first year of continuous full ELF operations.

## V. NEST ACTIVITY RESULTS

**Hypothesis 5. The duration of round leaf (LO) foraging trips remains the same when bees are exposed to ELF EM fields.**

During the 1987 field season we noticed that LO trip durations increased with each successive trip after the bee lays her egg. In 1987, however, we did not keep track of which LO trips in the capping sequence were being timed. Occasionally, we could deduce which trip had started the timings. Just before collecting the first LO in the cap after laying her egg, the female makes a series of very rapid flights in and out of the nest. Undergraduate observers refer to this behavior as "spazzing". Where rapid flights in and out of the nest, without a cargo, appear at the beginning of a series of 1987 LO timings, we have assumed that the first LO trip for the cell has been timed.

In 1988 we recorded the actual trip number for 73% of the capping sequences that were timed. In 1989 and 1990, we were even more diligent, recording actual trip numbers for every cell cap timed. In our analyses residuals fit a normal distribution only when we restricted the analysis to no more than the first 8 trips, and only when we used a  $\ln(\ln)$  transformation of LO trip durations.

Figs. 24 and 25 summarize mean LO durations for the four sites and four years, based on data analyzed in two GLM analyses. The first involves mean of trip ranks 1-3 for each cell capping bout. The second involves trip ranks as a covariate, and nest number (=cell capping bout) as a class variable in the model. If ELF EM fields were having an effect on LO durations, we would expect to see mean durations increasing (or possibly decreasing) for the treatment sites but not for the control sites since 1989. This does not seem to be the case. LO durations tend to be greater at the experimental sites across all years, even before the antenna became fully operational. Furthermore, mean LO durations have tended to fluctuate around a narrow range of means from year to year. (There was a greater spread between sites in 1987 than in subsequent years because of smaller sample sizes, and more LO durations at the higher trip ranks.)

Results of the GLM analysis of the mean of trips 1-3 are summarized in Table 26. Results of the GLM analysis of trip ranks 1-8, including nest number as a class variable, are found in Tables 27 - 30. When nest number is a class variable, the proportion of the variability explained by the model ( $r^2$ , Tables 27-30) greatly increases compared with the models used in previous years. In the first model (Mean of trip durations, Table 26),  $r^2$  is lower, but the error variance is a measure of between nest variability. As indicated in Figs. 24 and 25, experimental vs. control areas did not contribute significantly to the variability. Since we now have two years of

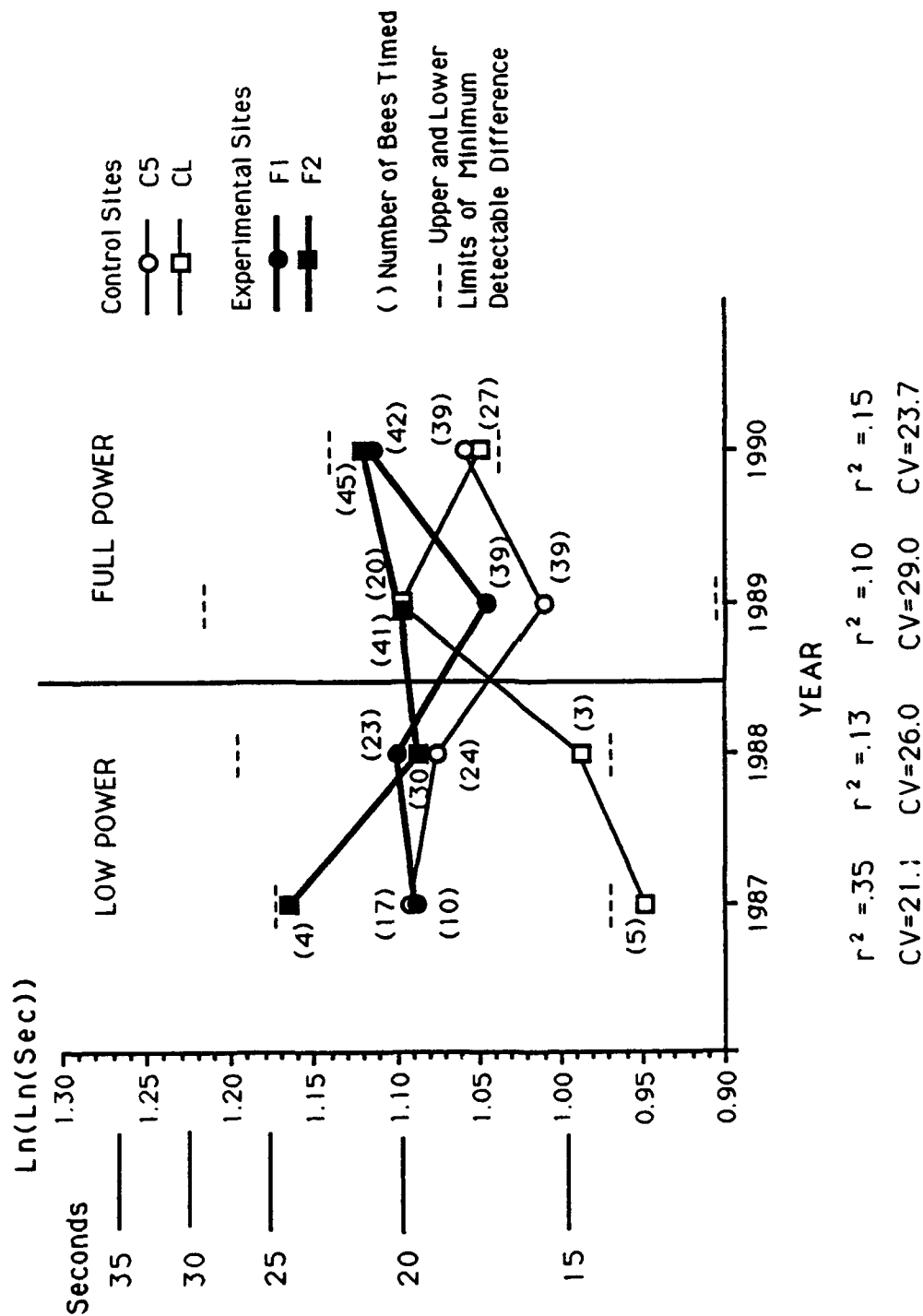


FIGURE 24. Mean duration of LO collecting trips for the first three leaf collecting trips in a cell cap. Numbers of bees timed in parenthesis; horizontal dashes indicate upper and lower limits to the minimum detectable difference between experimental and control areas for each year.

TABLE 26: GLM of mean of ln ln transformed LO trip durations; trips 1-3 for each timed M. inermis, 1987-90.

MEAN LO TRIP DURATIONS

| Source of variation                                      | df  | SS    | F    | P>F     |
|--|-----|-------|------|---------|
| Year   | 3   | 0.15  | 1.03 | 0.4074  |
| Exp  | 1   | 0.28  | 4.42 | 0.1704  |
| Site[Exp]  | 2   | 0.13  | 0.82 | 0.4430  |
| Exp*Year   | 3   | 0.67  | 0.35 | 0.7981  |
| Observer[Year]   | 14  | 0.69  | 0.64 | 0.8345  |
| Time of day[Year]  | 4   | 0.24  | 0.78 | 0.5412  |
| Time*Time[Year]  | 4   | 0.25  | 0.82 | 0.5142  |
| Date[Year]   | 4   | 1.25  | 4.01 | 0.0034* |
| Model  | 35  | 4.20  | 1.54 | 0.0282* |
| Error  | 372 | 28.90 |      |         |
| $\bar{X} = 1.07$ (18.4 sec.)      CV = 26.0 $r^2 = 0.13$ |     |       |      |         |

Parameter Estimates :

| Date[Year] |        | T for H <sub>0</sub> :<br>Parameter = 0 | PR>  T |
|------------|--------|---|--------|
| 1987       | 0.0021 | 0.82                                    | 0.4115 |
| 1988       | 0.0023 | 1.15                                    | 0.2515 |
| 1989       | 0.0021 | 1.55                                    | 0.1223 |
| 1990       | 0.0036 | 3.42                                    | 0.0007 |

data with the ELF antenna on full power, including continuous full power in 1990, these negative results suggest that the antenna is not affecting LO trip durations.

As expected, trip rank contributed significantly to variability in LO trip durations in the second analysis (Tables 27-30). Time of day contributed to variability in LO durations only when trips 1-8 are included in the analysis, and only in 1988 and 1990. This suggests that temperature or other weather parameters may sometimes affect LO durations. Date of the timing was significant only in 1990.

Minimum detectable differences between control and experimental sites were calculated separately for each year and plotted on Figures 24 and 25. Observed differences between experimental and control areas have always been less than the minimum detectable difference. Minimum detectable differences are smaller for the analysis that incorporates Nest number as a class variable (Fig. 25) than for the analysis of mean LO durations for each nest (Fig. 24).

1991 will be the final year for collecting data on LO durations. If LO durations are significantly different between experimental and control areas in 1991 due to an increase in durations at the experimental sites, this may suggest a slow change (possibly genetic) is occurring in the experimental sites due to ELF EM fields that has not been significant up to now. However, this possible result seems unlikely based on 1989 and 1990 results.

The data prior to 1987 will be reanalyzed using the same GLM procedures. At the time of this writing, however the Trip Rank variable has not yet been created for this data.

Weather data, and presence or absence of ELF EM fields during the LO trip are variables being added to our nest activity SAS data set, so we can incorporate them into our model of nest activity in the future.



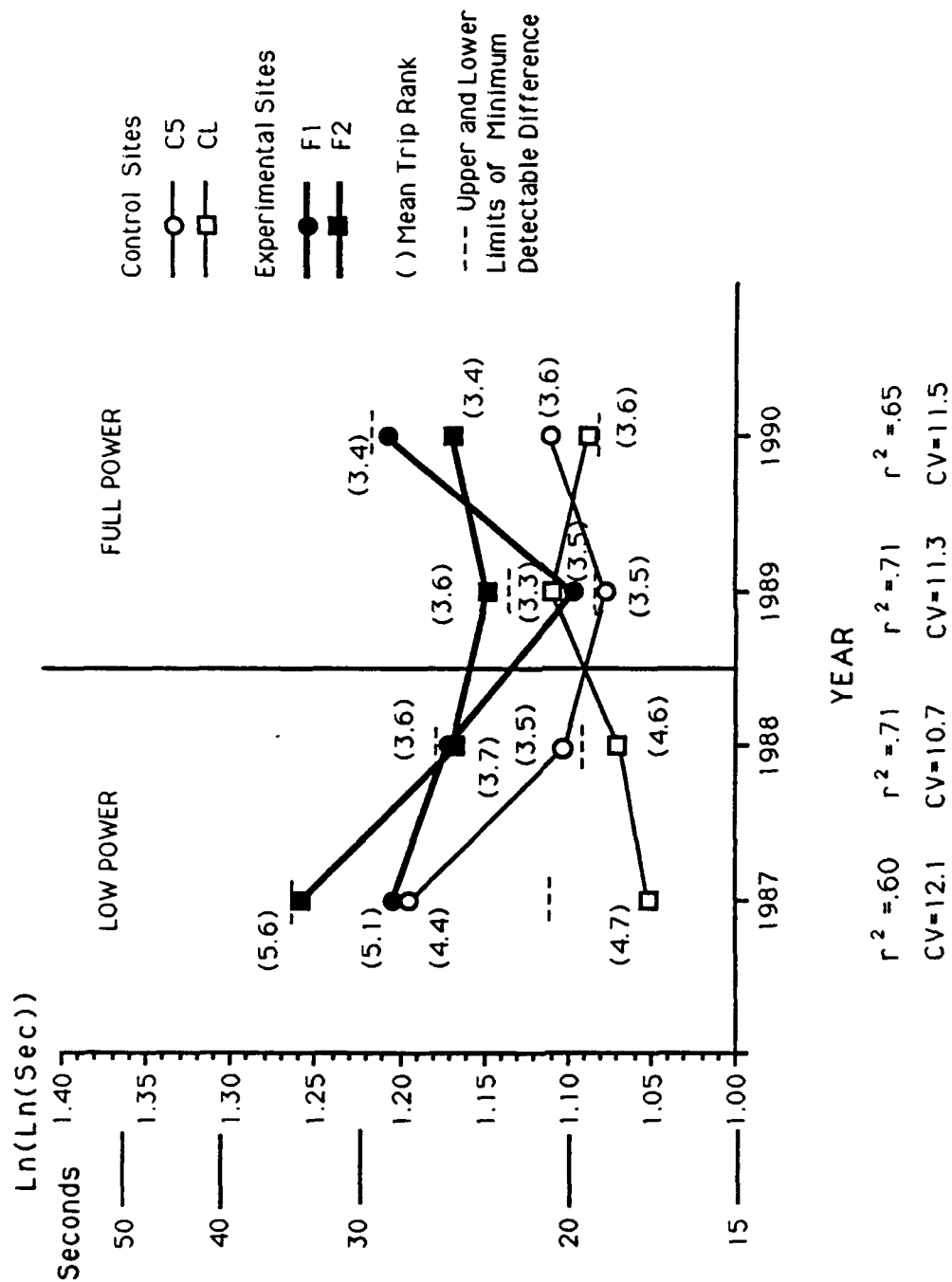


FIGURE 25. Duration of LO collecting trips based on analysis of first eight trips; nest number included as a class variable. Mean trip rank in parenthesis; horizontal dashes indicate upper and lower limits to the minimum detectable difference between experimental and control areas for each year.

TABLE 27: GLM of ln ln transformed LO trip durations for M. inermis, 1987; trips 1-8.

LO TRIP DURATIONS

| Source of variation                                   | df  | SS   | F    | P>F       |
|---|-----|------|------|-----------|
| Exp   | 1   | 0.10 | 0.89 | 0.4447    |
| Site[Exp]   | 2   | 0.22 | 5.30 | 0.0057*   |
| Nest Number[Site*Exp]                                 | 43  | 3.01 | 3.39 | 0.0001*** |
| Trip rank[Site*Exp]                                   | 4   | 0.72 | 8.76 | 0.0001*** |
| Time*Time   | 1   | 0.14 | 6.90 | 0.0093*   |
| Model   | 56  | 6.34 | 5.49 | 0.0001*** |
| Error   | 207 | 4.27 |      |           |
| $\bar{X} = 1.19$ (26.5 sec.) $CV = 12.1$ $r^2 = 0.60$ |     |      |      |           |

| Parameter    | Estimate | T for $H_0$ :<br>Parameter = 0 | PR >  T   |
|--------------|----------|--------------------------------|-----------|
| Site[Exp] C5 | 0.0      | --                             | --        |
| CL           | -1.5857  | -2.64                          | 0.0089*   |
| F1           | -2.3394  | -2.40                          | 0.0173*   |
| F2           | 0.0      | --                             | --        |
| Time *Time   | -0.0227  | -2.63                          | 0.0093*   |
| Trip rank    |          |                                |           |
| Site[Exp] C5 | 0.0878   | 5.44                           | 0.0001*** |
| CL           | 0.0500   | 3.56                           | 0.0005*** |
| F1           | 0.0844   | 5.53                           | 0.0001*** |
| F2           | 0.0540   | 3.26                           | 0.0013*   |

TABLE 28: GLM of ln ln transformed LO trip durations for M. inermis, 1988; trips 1-8.

LO TRIP DURATIONS

| Source of variation         | df        | SS           | F     | P>F       |
|-----------------------------|-----------|--------------|-------|-----------|
| Exp                         | 1         | 0.00         | 0.02  | 0.9044    |
| Site[Exp]                   | 2         | 0.11         | 3.78  | 0.0237*   |
| Nest Number[Site*Exp]       | 73        | 9.08         | 8.25  | 0.0 ***   |
| Trip rank[Site*Exp]         | 4         | 1.15         | 19.15 | 0.0001*** |
| Observer                    | 4         | 0.43         | 7.21  | 0.0001*** |
| Time*Time                   | 1         | 0.32         | 20.96 | 0.0001*** |
| Date                        | 1         | 0.01         | 0.74  | 0.3890    |
| Model                       | 86        | 13.55        | 10.46 | 0.0 ***   |
| Error                       | 372       | 5.60         |       |           |
| $\bar{X} = 1.1$ (23.1 sec.) | CV = 10.7 | $r^2 = 0.71$ |       |           |

| Parameter    | Estimate | T for $H_0$ :<br>Parameter = 0 | PR >  T   |
|--------------|----------|--------------------------------|-----------|
| Site[Exp] C5 | 0.0      | --                             | --        |
| CL           | 0.3827   | 2.43                           | 0.0154*   |
| F1           | 0.3828   | 1.46                           | 0.1456    |
| F2           | 0.0      | --                             | --        |
| Time *Time   | 0.0057   | 4.58                           | 0.0001*** |
| Trip rank    |          |                                |           |
| Site[Exp] C5 | 0.0261   | 3.96                           | 0.0001*** |
| CL           | -0.0044  | -0.33                          | 0.7388    |
| F1           | 0.0276   | 4.40                           | 0.0001*** |
| F2           | 0.0399   | 6.88                           | 0.0001*** |

TABLE 29: GLM of ln ln transformed LO trip durations for M. inermis, 1989; trips 1-8.

LO TRIP DURATIONS

| Source of variation   | df  | SS    | F     | P>F       |
|---|-----|-------|-------|-----------|
| Exp   | 1   | 0.00  | 0.01  | 0.9293    |
| Site[Exp]   | 2   | 0.08  | 2.57  | 0.0773    |
| Nest Number[Site*Exp]                                       | 132 | 19.27 | 9.24  | 0.0 ***   |
| Trip rank[Site*Exp]   | 4   | 1.24  | 19.67 | 0.0001*** |
| Observer  | 1   | 0.07  | 4.50  | 0.0344    |
| Time*Time   | 1   | 0.0   | 0.01  | 0.9080    |
| Model   | 144 | 23.97 | 10.54 | 0.0 ***   |
| Error   | 609 | 9.62  |       |           |
| $\bar{X} = 1.1$ (20.7 sec.) $CV = 11.35$ $r^2 \approx 0.71$ |     |       |       |           |

| Parameter    | Estimate | T for $H_0$ :<br>Parameter = 0 | PR >  T   |
|--------------|----------|--------------------------------|-----------|
| Trip rank    |          |                                |           |
| Site[Exp] C5 | 0.0472   | 6.22                           | 0.0001*** |
| CL           | 0.0129   | 1.40                           | 0.1606    |
| F1           | 0.0508   | 7.19                           | 0.0001*** |
| F2           | 0.0477   | 6.61                           | 0.0001*** |

TABLE 30: GLM of ln ln transformed LO trip durations for M. inermis, 1990; trips 1-8.

LO TRIP DURATIONS

| Source of variation                                     | df  | SS    | F     | P>F       |
|---|-----|-------|-------|-----------|
| Exp   | 1   | 0.31  | 1.11  | 0.4029    |
| Site[Exp]   | 2   | 0.56  | 16.04 | 0.0001**  |
| Nest Number[Site*Exp]                                   | 145 | 14.14 | 5.55  | 0.0 ***   |
| Trip rank[Site*Exp]                                     | 4   | 0.55  | 7.81  | 0.0001*** |
| Observer  | 2   | 0.34  | 9.71  | 0.0001*** |
| Time*Time   | 1   | 0.38  | 21.50 | 0.0001*** |
| Date  | 1   | 0.32  | 18.26 | 0.0001*** |
| Model   | 157 | 21.37 | 7.74  | 0.0 ***   |
| Error   | 658 | 11.56 |       |           |
| $\bar{X} = 1.1$ (20.7 sec.)      CV = 11.5 $r^2 = 0.65$ |     |       |       |           |

| Parameter    | Estimate | T for $H_0$ :<br>Parameter = 0 | PR >  T   |
|--------------|----------|--------------------------------|-----------|
| Date         | 0.3067   | 4.27                           | 0.0001*** |
| Site[Exp] C5 | 0.0      | --                             | --        |
| CL           | -6.865   | -4.37                          | 0.0001*** |
| F1           | -4.260   | -4.50                          | 0.0001*** |
| F2           | 0.0      | --                             | --        |
| Time *Time   | 0.0174   | 4.64                           | 0.0001*** |
| Trip rank    |          |                                |           |
| Site[Exp] C5 | 0.0142   | 1.89                           | 0.0597    |
| CL           | 0.0131   | 1.64                           | 0.1010    |
| F1           | 0.0440   | 5.47                           | 0.0001*** |
| F2           | 0.0162   | 2.21                           | 0.0275*   |

## VI. EMERGENCE RESULTS

For the most part, both species of Megachile in our study are univoltine, having only one generation per year. There have been a few exceptions: In M. relativa nests, 2 - 22% of all M. relativa and 11 - 26% of all Coelioxys moesta Cresson emergences occur in August and September (Table 31). Far fewer instances of bivoltinism occur in M. inermis nests (Table 32). Early emergences do not overwinter, and are not included in the analysis described below.

### Hypothesis 6. Overwintering mortality of megachilid bees is unchanged by exposure to ELF EM fields.

Prior to emergence as an adult in the Spring, Megachile are subject to a variety of sources of mortality. The egg may fail to hatch, or the larva may die of unknown causes during the summer. The prepupa may die during the winter. The pupa may fail to eclose in the spring. A number of parasites may attack the Megachile egg, larva, or pupa at various times in its development. Parasites include the cuckoo bees, Coelioxys moesta on M. relativa and C. funeraria Smith on both Megachile spp.; the flies Anthrax irroratus irroratus Say and Anthrax pluto pluto Weidemann; chalcid and leucopsid wasps.

The percent mortality due to various causes is presented by site and year for M. relativa and M. inermis in Tables 33 and 34 and Figs. 26 and 27. These tables show that pre-overwintering mortality (mortality of eggs and larvae) was greater in 1987 than in previous years (M. relativa), and even greater in 1988 (both species). This may be due in part to the change in protocol in 1987, leaving nests to overwinter in the field rather than bringing them to Channing. However, pre-overwintering mortality decreased in 1989. Weather patterns are undoubtedly also involved. High pre-overwintering mortality in 1988 nests was probably due to dry, hot summer weather. Unusually cold spring weather contributed to overwintering mortality in 1988 and 1989. Numerous summer rainfalls may have caused higher pre-overwintering mortality in 1987 as compared to earlier years. Similarly, proportion of adults emerging was particularly low for 1988 (M. relativa) and 1989 (both species) nests. The proportion of cells with prepupal mortality (i.e., the overwintering mortality) was low at all sites and in all years. Prior to 1989 it varied between 0.014 and 0.134 (M. relativa) and from 0 to 0.165 (M. inermis). In 1989, prepupal mortality reached 0.188 for M. relativa and 0.240 for M. inermis at F2 (Table 34).

TABLE 31: Late Summer Emergences (% bivoltinism) of M. relativa and Coelioxys moesta.

| <u>M. relativa</u> |                                 |                                      |         |                                 |  |
|--------------------|---------------------------------|--------------------------------------|---------|---------------------------------|--|
| Year               | cells emerging /<br>late summer | total cells<br>emerging <sup>1</sup> | (%)     | nests emerging /<br>late summer | total nests<br>emerging <sup>1</sup> (%) |
| 1987               | 33/629                          |                                      | (5.2%)  | 7/186                           | (3.8%)                                   |
| 1988               | 13/285                          |                                      | (4.6%)  | 7/144                           | (4.9%)                                   |
| 1989               | 112/515                         |                                      | (21.7%) | 24/166                          | (14.5%)                                  |
| 1990               | 28/1180 <sup>3</sup>            |                                      | (2.4%)  | 12/295 <sup>3</sup>             | (4.1%)                                   |

| <u>Coelioxys moesta</u> |                                 |                                      |         |                                 |  |
|-------------------------|---------------------------------|--------------------------------------|---------|---------------------------------|--|
| Year                    | cells emerging /<br>late summer | total cells<br>emerging <sup>2</sup> | (%)     | nests emerging /<br>late summer | total nests<br>emerging <sup>2</sup> (%) |
| 1987                    | 11/99                           |                                      | (11.1%) | 10/77                           | (13.0%)                                  |
| 1988                    | 10/87                           |                                      | (11.5%) | 8/62                            | (12.9%)                                  |
| 1989                    | 18/71                           |                                      | (25.4%) | 11/50                           | (22.0%)                                  |
| 1990                    | 3/?                             |                                      |         | 2/?                             |  |

<sup>1</sup>Total cells or nests with adult M. relativa.

<sup>2</sup>Total cells or nests with adult Coelioxys in M. relativa nests.

<sup>3</sup>Estimate, since spring emergence has not yet taken place.

TABLE 32: Late Summer Emergences (% bivoltinism) of M. inermis and Coelioxys spp.

| <u>M. inermis</u> |  |        |  |        |
|-------------------|--|--------|--|--------|
| Year              | cells emerging<br>late summer / total cells<br>emerging <sup>1</sup> | (%)    | nests emerging<br>late summer / total nests<br>emerging <sup>1</sup> | (%)    |
| 1987              | 2/1,011  | (0.2%) | 1/262  | (0.4%) |
| 1988              | 0/562  | (0.0%) | 0/168  | (0.0%) |
| 1989              | 4/1190   | (0.3%) | 1/400  | (0.3%) |
| 1990              | 2/2636 <sup>3</sup>  | (0.1%) | 1/659 <sup>3</sup>   | (0.2%) |

| <u>Coelioxys</u> spp. |  |        |  |        |
|-----------------------|--|--------|--|--------|
| Year                  | cells emerging<br>late summer / total cells<br>emerging <sup>2</sup> | (%)    | nests emerging<br>late summer / total nests<br>emerging <sup>2</sup> | (%)    |
| 1987                  | 0/62   | (0.0%) | 0/48   | (0.0%) |
| 1988                  | 0/18   | (0.0%) | 0/16   | (0.0%) |
| 1989                  | 0/86   | (0.0%) | 0/67   | (0.0%) |
| 1990                  | 0/?  | (0.0%) | 0/?  | (0.0%) |

<sup>1</sup>Total cells or nests with adult M. inermis.

<sup>2</sup>Total cells or nests with adult Coelioxys in M. inermis nests.

<sup>3</sup>Estimate, since spring emergence has not yet taken place.



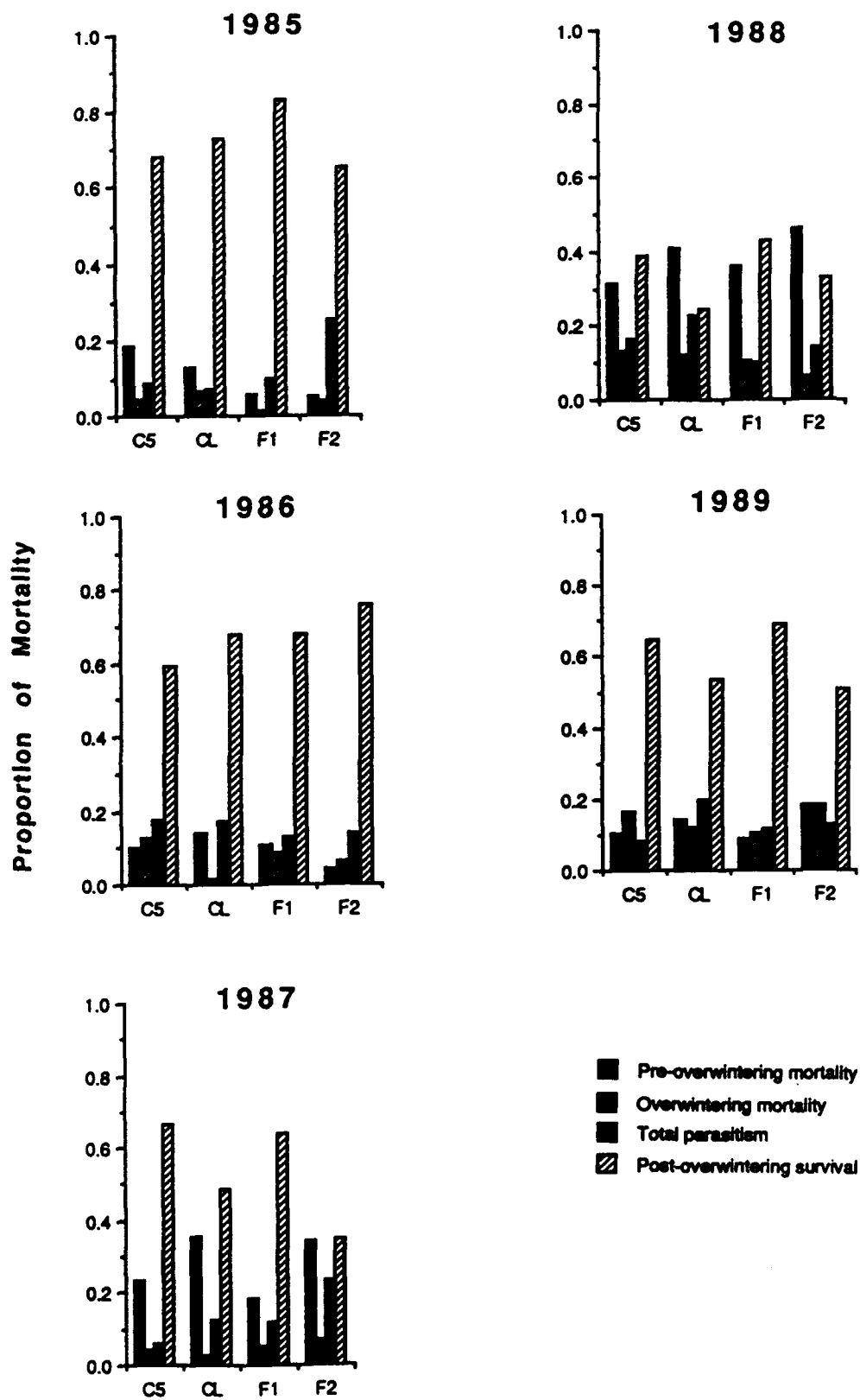


FIGURE 26. Proportion of mortality from various sources by site, *M. relativa*.

TABLE 33: Proportion of M. relativa mortality from various sources by site.

| Stage or source<br>of mortality              | SITE             |                  |                  |                  |
|--|------------------|------------------|------------------|------------------|
|  | C5               | CL               | F1               | F2               |
| 1985   |                  |                  |                  |                  |
| Pre-overwintering<br>(egg & larvae)          | 0.185            | 0.131            | 0.059            | 0.053            |
| Overwintering<br>(Prepupae)                  | 0.045            | 0.069            | 0.014            | 0.041            |
| Total parasitism<br>( <u>Coelioxys</u> only) | 0.089<br>(0.076) | 0.073<br>(0.053) | 0.100<br>(0.089) | 0.254<br>(0.234) |
| Post-overwintering<br>Survival*              | 0.681            | 0.727            | 0.827            | 0.652            |
| 1986   |                  |                  |                  |                  |
| Pre-overwintering<br>(egg & larvae)          | 0.104            | 0.138            | 0.109            | 0.041            |
| Overwintering<br>(Prepupae)                  | 0.130            | 0.015            | 0.085            | 0.063            |
| Total parasitism<br>( <u>Coelioxys</u> only) | 0.169<br>(0.130) | 0.177<br>(0.138) | 0.127<br>(0.127) | 0.149<br>(0.114) |
| Post-overwintering<br>Survival*              | 0.597            | 0.669            | 0.679            | 0.749            |
| 1987   |                  |                  |                  |                  |
| Pre-overwintering<br>(egg & larvae)          | 0.235            | 0.354            | 0.186            | 0.344            |
| Overwintering<br>(Prepupae)                  | 0.041            | 0.030            | 0.055            | 0.070            |
| Total parasitism<br>( <u>Coelioxys</u> only) | 0.058<br>(0.041) | 0.128<br>(0.122) | 0.118<br>(0.110) | 0.234<br>(0.195) |
| Post-overwintering<br>Survival*              | 0.665            | 0.488            | 0.640            | 0.352            |
| 1988   |                  |                  |                  |                  |
| Pre-overwintering<br>(egg & larvae)          | 0.313            | 0.407            | 0.363            | 0.464            |
| Overwintering<br>(Prepupae)                  | 0.134            | 0.122            | 0.106            | 0.064            |
| Total parasitism<br>( <u>Coelioxys</u> only) | 0.167<br>(0.138) | 0.228<br>(0.195) | 0.099<br>(0.070) | 0.144<br>(0.128) |
| Post-overwintering<br>Survival*              | 0.386            | 0.244            | 0.433            | 0.328            |

(continued)

TABLE 33 (continued)

| Stage or source<br>of mortality              | SITE             |                  |                  |                  |
|--|------------------|------------------|------------------|------------------|
|  | C5               | CL               | F1               | F2               |
| 1989   |                  |                  |                  |                  |
| Pre-overwintering<br>(egg & larvae)          | 0.106            | 0.127            | 0.080            | 0.176            |
| Overwintering<br>(Prepupae)                  | 0.165            | 0.127            | 0.105            | 0.188            |
| Total parasitism<br>( <u>Coelioxys</u> only) | 0.083<br>(0.071) | 0.206<br>(0.139) | 0.117<br>(0.111) | 0.130<br>(0.092) |
| Post-overwintering<br>Survival*              | 0.646            | 0.539            | 0.698            | 0.506            |

\* Includes cells with dead pupae, dead adults, and successfully emerging adult M. relativa.

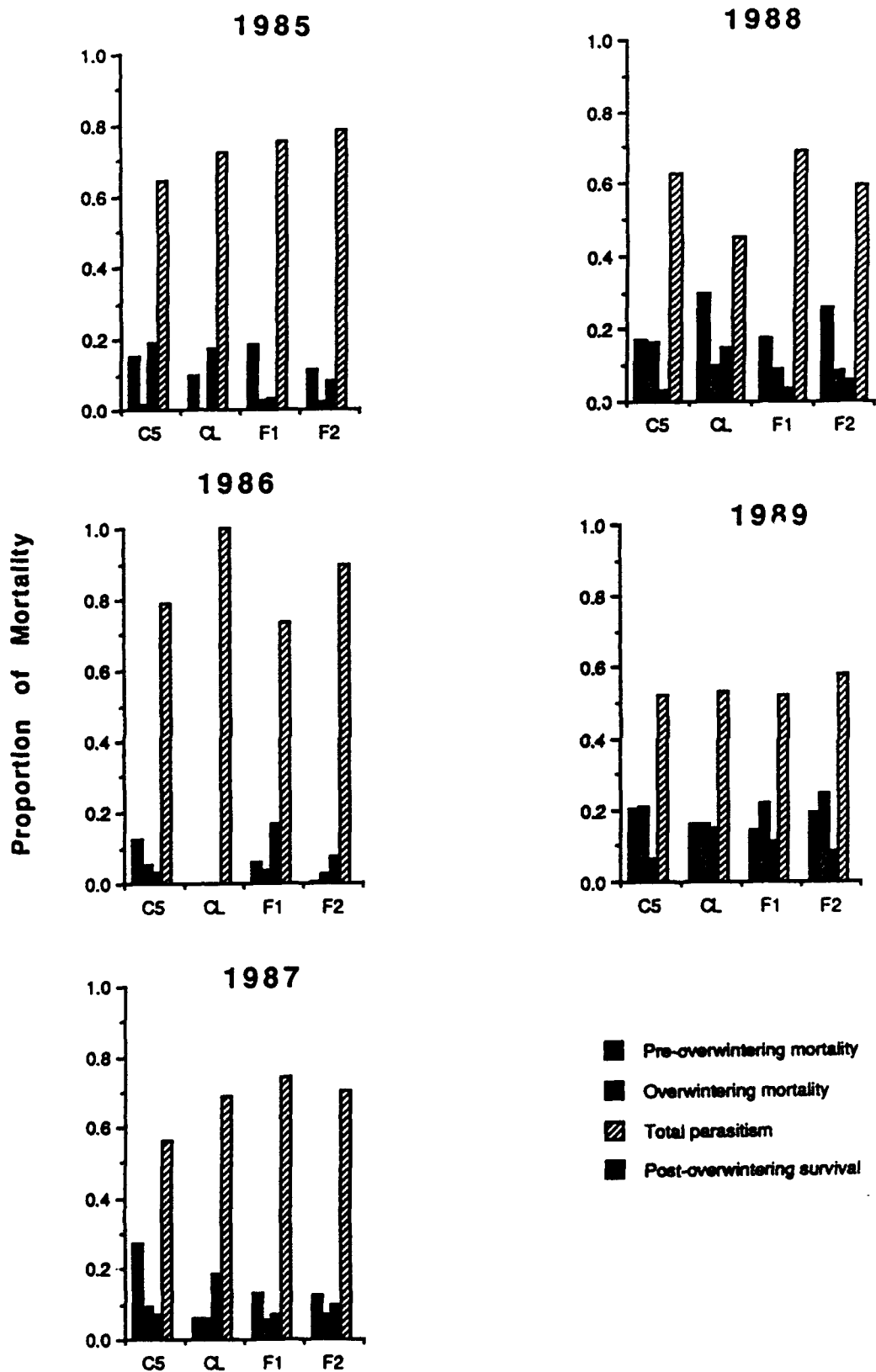


FIGURE 27. Proportion of mortality from various sources by site, *M. inermis*.

TABLE 34: Proportion of M. inermis mortality from various sources by site.

| Stage or source<br>of mortality              | SITE             |                  |                  |                  |
|--|------------------|------------------|------------------|------------------|
|  | C5               | CL               | F1               | F2               |
| 1985   |                  |                  |                  |                  |
| Pre-overwintering<br>(egg & larvae)          | 0.151            | 0.098            | 0.184            | 0.114            |
| Overwintering<br>(Prepupae)                  | 0.019            | 0.000            | 0.028            | 0.022            |
| Total parasitism<br>( <u>Coelioxys</u> only) | 0.189<br>(0.170) | 0.176<br>(0.059) | 0.031<br>(0.011) | 0.079<br>(0.035) |
| Post-overwintering<br>Survival*              | 0.641            | 0.725            | 0.757            | 0.786            |
| 1986   |                  |                  |                  |                  |
| Pre-overwintering<br>(egg & larvae)          | 0.119            | 0.000            | 0.061            | 0.004            |
| Overwintering<br>(Prepupae)                  | 0.051            | 0.000            | 0.038            | 0.026            |
| Total parasitism<br>( <u>Coelioxys</u> only) | 0.068<br>(0.034) | 0.000<br>(0.000) | 0.167<br>(0.038) | 0.073<br>(0.009) |
| Post-overwintering<br>Survival*              | 0.763            | 1.000            | 0.735            | 0.897            |
| 1987   |                  |                  |                  |                  |
| Pre-overwintering<br>(egg & larvae)          | 0.272            | 0.062            | 0.131            | 0.124            |
| Overwintering<br>(Prepupae)                  | 0.092            | 0.062            | 0.055            | 0.069            |
| Total parasitism<br>( <u>Coelioxys</u> only) | 0.072<br>(0.048) | 0.186<br>(0.088) | 0.070<br>(0.032) | 0.103<br>(0.041) |
| Post-overwintering<br>Survival*              | 0.564            | 0.690            | 0.744            | 0.704            |
| 1988   |                  |                  |                  |                  |
| Pre-overwintering<br>(egg & larvae)          | 0.174            | 0.300            | 0.175            | 0.260            |
| Overwintering<br>(Prepupae)                  | 0.165            | 0.100            | 0.087            | 0.085            |
| Total parasitism<br>( <u>Coelioxys</u> only) | 0.035<br>(0.009) | 0.150<br>(0.150) | 0.044<br>(0.000) | 0.060<br>(0.025) |
| Post-overwintering<br>Survival*              | 0.626            | 0.450            | 0.694            | 0.595            |

continued

TABLE 34 continued

| Stage or source<br>of mortality              | SITE             |                  |                  |                  |
|--|------------------|------------------|------------------|------------------|
|  | C5               | CL               | F1               | F2               |
| 1989   |                  |                  |                  |                  |
| Pre-overwintering<br>(egg & larvae)          | 0.183            | 0.156            | 0.130            | 0.171            |
| Overwintering<br>(Prepupae)                  | 0.214            | 0.167            | 0.213            | 0.240            |
| Total parasitism<br>( <u>Coelioxys</u> only) | 0.060<br>(0.360) | 0.156<br>(0.115) | 0.099<br>(0.042) | 0.062<br>(0.032) |
| Post-overwintering<br>Survival*              | 0.542            | 0.521            | 0.558            | 0.527            |

\* Includes cells with dead pupae, dead adults, and successfully emerging adult M. inermis.

There are several ways that one can measure overwintering mortality, and several problems that must be dealt with in analyzing it. First, we equate overwintering mortality with the prepupal stage, but actually the prepupa lasts for a longer time than just the winter. The prepupal stage begins several weeks after the egg is laid, when the larva has finished eating its provisions. The prepupa defecates shortly after molting, and then spins a silken cocoon for overwintering that is surrounded by fecal pellets. Thus the prepupal stage may begin as early as mid-summer. It lasts until pupation in the spring. This occurs typically in mid to late May, although we have opened few cells to find out, because this is likely to increase mortality. In spring 1989 and 1990, the prepupal stage for nests constructed in 1988 and 1989 probably lasted into June, due to cool weather and a change in protocol to a shady outdoor emergence site. Emergence was delayed in 1989 and 1990 until July. Figs. 28 - 30 compare emergence of 1987 - 1989 nests in spring 1988, 1989, and 1990 respectively.

There is no way to separate prepupal mortality that occurs during the winter from prepupal mortality that occurs in summer, fall or spring. 1987 - 1989 nests were left at the sites where they were constructed during the entire prepupal stage except for the last few weeks, when nests were returned to Crystal Falls for nest architecture measurements. Thus, the effects of ELF EM fields on prepupal mortality any time before May are tested by our protocol.

Prior to 1989, pupation and emergence took place in the lab where indoor microclimate and 60 hz EM fields could affect pupal and adult mortality. Starting in 1989, the effects of 60 hz EM fields were minimized by moving emergence of all cells to an outdoor holding site. We have no way of knowing how many adult bees would have successfully emerged at the study sites, but the number of cells that survive past the prepupal stage provides an upper limit. Therefore, we combine pupae, adults that die in the cocoon, and adults that successfully emerge, into one "post-overwintering" category.

The prepupal stage has the longest duration of all the developmental stages of these univoltine species. However, mortality is usually greater in the pre-overwintering egg and larval stages. Mortality of these early stages show differences between years and sites (Tables 33, 34, Figure 26, 27) that could make it difficult to detect differences due to ELF EM fields. Therefore, we propose restating our hypothesis as: **Given that a bee survives to the prepupal stage, the probability that it will not survive past the prepupal stage does not change in the presence of ELF EM fields.** Thus, we analyze proportion of mortality in the prepupal stage, calculated as the number of cells with a dead prepupa divided by the sum of cells with prepupae or post-overwintering bees. Cells containing egg and larval mortality are not included.

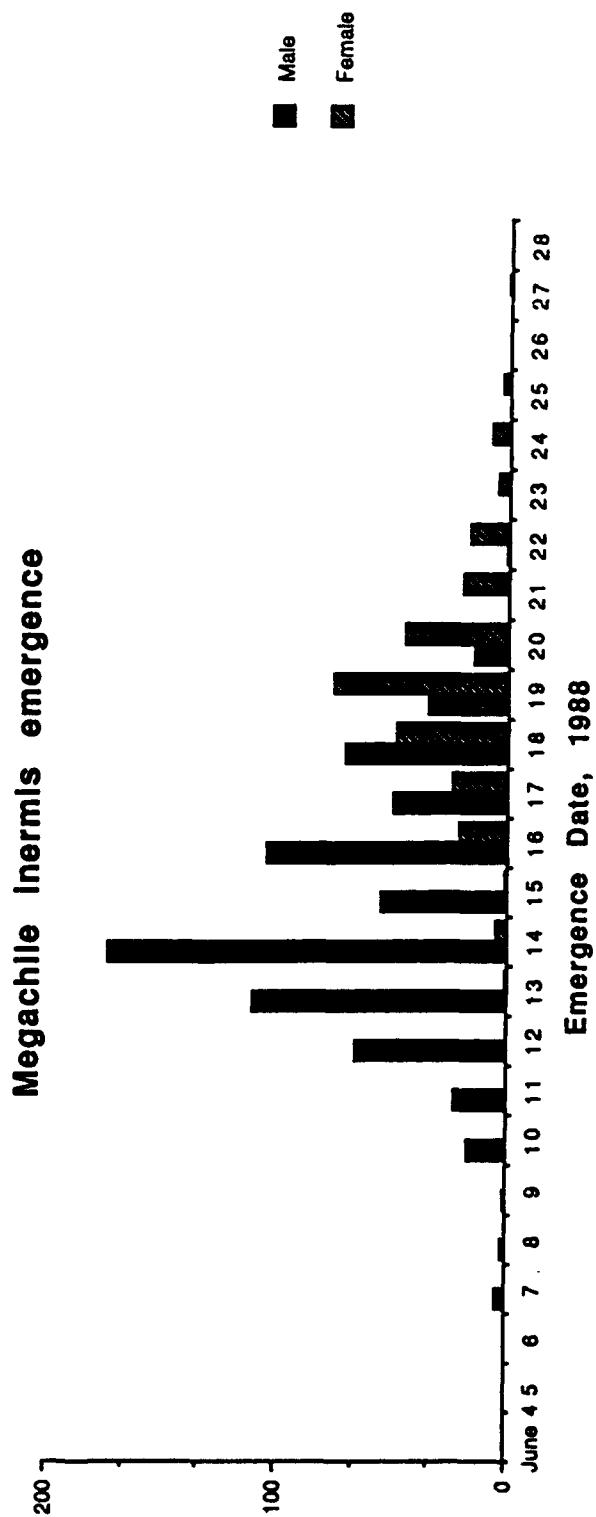
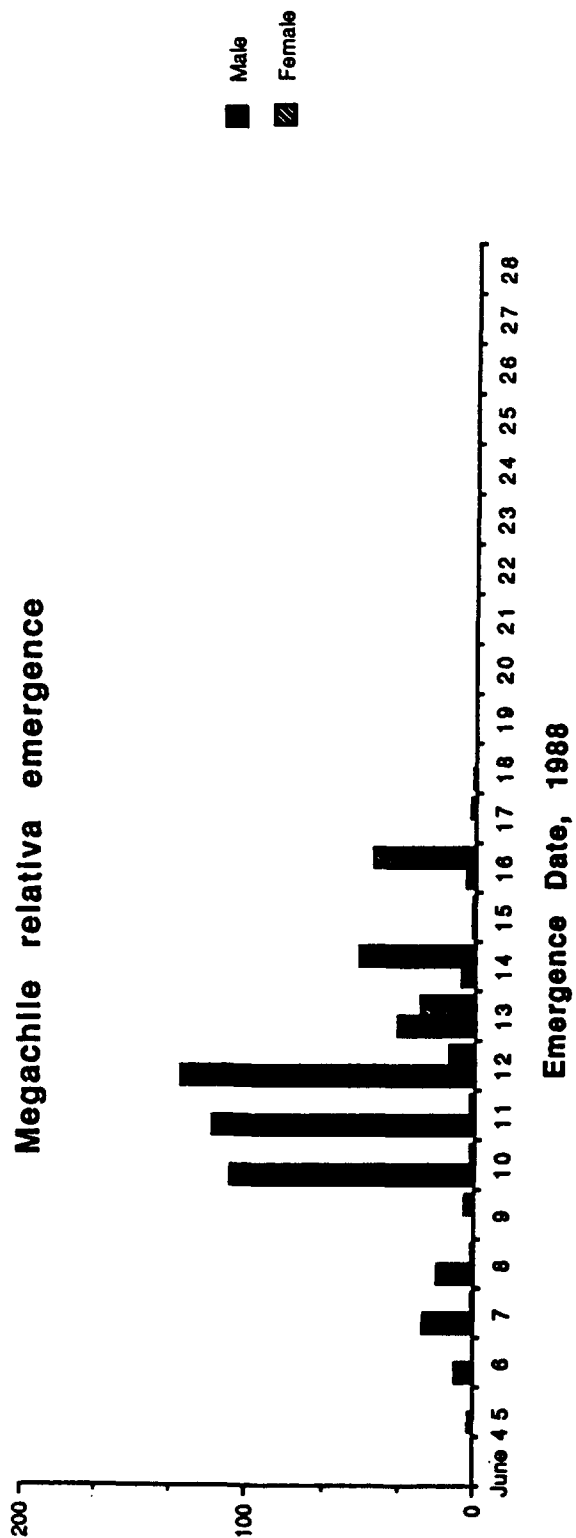
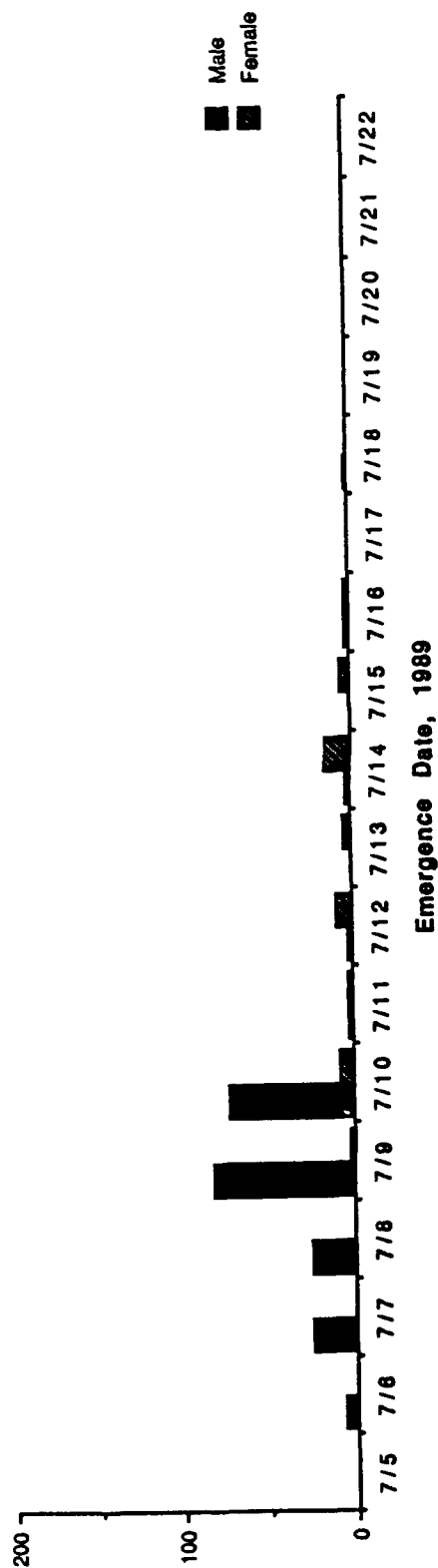


FIGURE 28. Phenology of emergence, 1987 nests emerging in 1988.



### Megachille relativa emergence



### Megachille inermis emergence

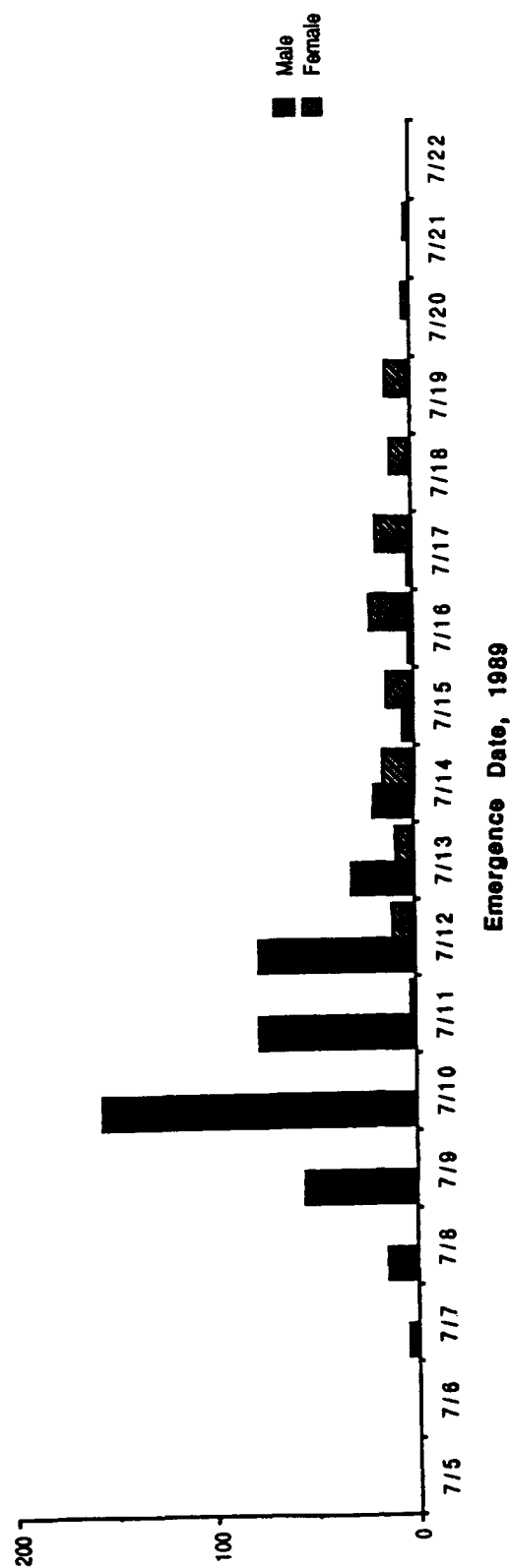


FIGURE 29. Phenology of emergence, 1988 nests emerging in 1989.

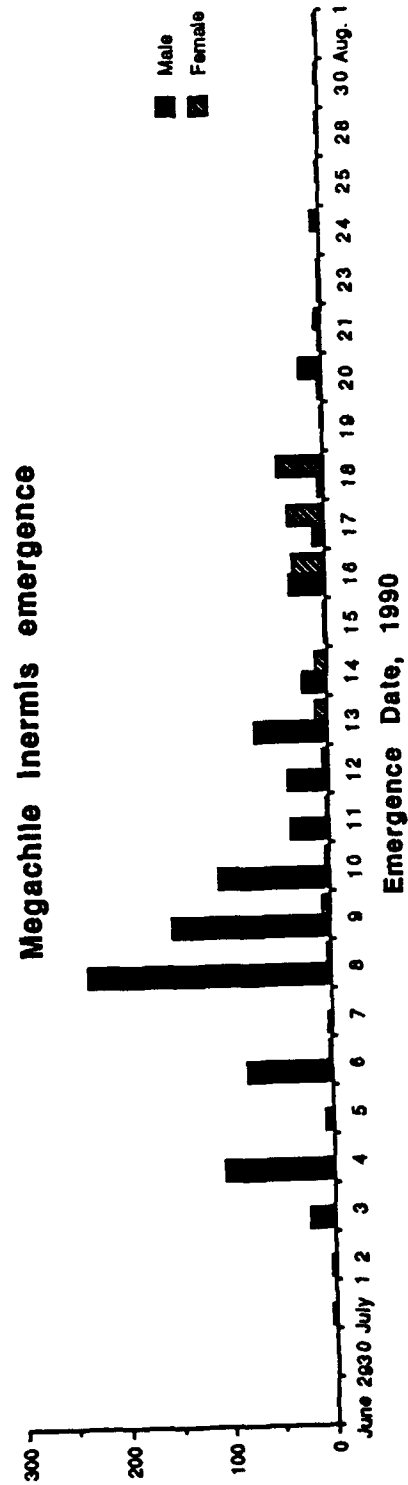


FIGURE 30. Phenology of emergence, 1989 nests emerging in 1990.

Parasites present another problem. It is easy to distinguish adult and pupal Megachile from adult and pupal parasites. However, we are unable to distinguish prepupae of Megachile from prepupae of the cuckoo bee, Coelioxys (also in the Megachilidae). The Coelioxys larva kills its host larva or egg, and feeds on the provisions in the cell. Like the host bee, Coelioxys overwinters in the prepupal stage. When testing the hypothesis above, the number of cells with dead prepupae should be reduced by the percentage of cells that are parasitized by Coelioxys. We can estimate percent parasitism of prepupae from the proportion of adults that are parasites. This assumes that there is no differential mortality of parasites in the prepupal stage as compared with the adult stage.

In our first attempts to analyze prepupal mortality, however, we have not tried to separate Megachile and Coelioxys data. Rather, we assume that both genera are affected in the same ways, if at all, by ELF EM fields. This assumption is more likely to be true for two bee species in the Megachilid family, than for a bee and a fly or wasp parasite. We calculated proportion of cells with prepupal mortality for each site and year by dividing the number of cells containing dead prepupae (x) by all cells with Megachile or Coelioxys prepupae or post-overwintering stages (n):  $x/n$ . These proportions are graphed as percents in Figs. 31 and 32.

In 1989 nests, prepupal mortality often occurred in several cells in a row in a nest. Some of these cells had a partially formed pupa visible under the prepupal exoskeleton. These prepupae obviously died late in their development, just before pupation. We believe this occurred during the cold spring weather, particularly on May 10, when there was a snow storm. For 1989 nests in particular, prepupal mortality in a cell was probably not independent of prepupal mortality of other cells in the same nest, which were all at the same critical stage of development when cold weather occurred. Therefore, in addition to an analysis of prepupal mortality by cells, we have also analyzed prepupal mortality by nest. We calculated proportion of nests with prepupal mortality for each site and year by dividing the number of nests containing at least one dead prepupa (X) by all nests with at least one Megachile or Coelioxys prepupa or post-overwintering stage (N):  $X/N$ . These proportions were always much higher than the proportions of cells with prepupal mortality (Figs. 33 and 34).

Neither Exp nor Exp\*Year contributed significantly to variance in proportion of cells or nests with prepupal mortality for either M. relativa or M. inermis (Table 35 - 42). This suggests that exposure to ELF EM fields at half power during the winter of 1988-89 and at full power during the winter of 1989-90, did not affect overwintering mortality. However, we caution that the high prepupal mortality of 1988 and 1989 nests was

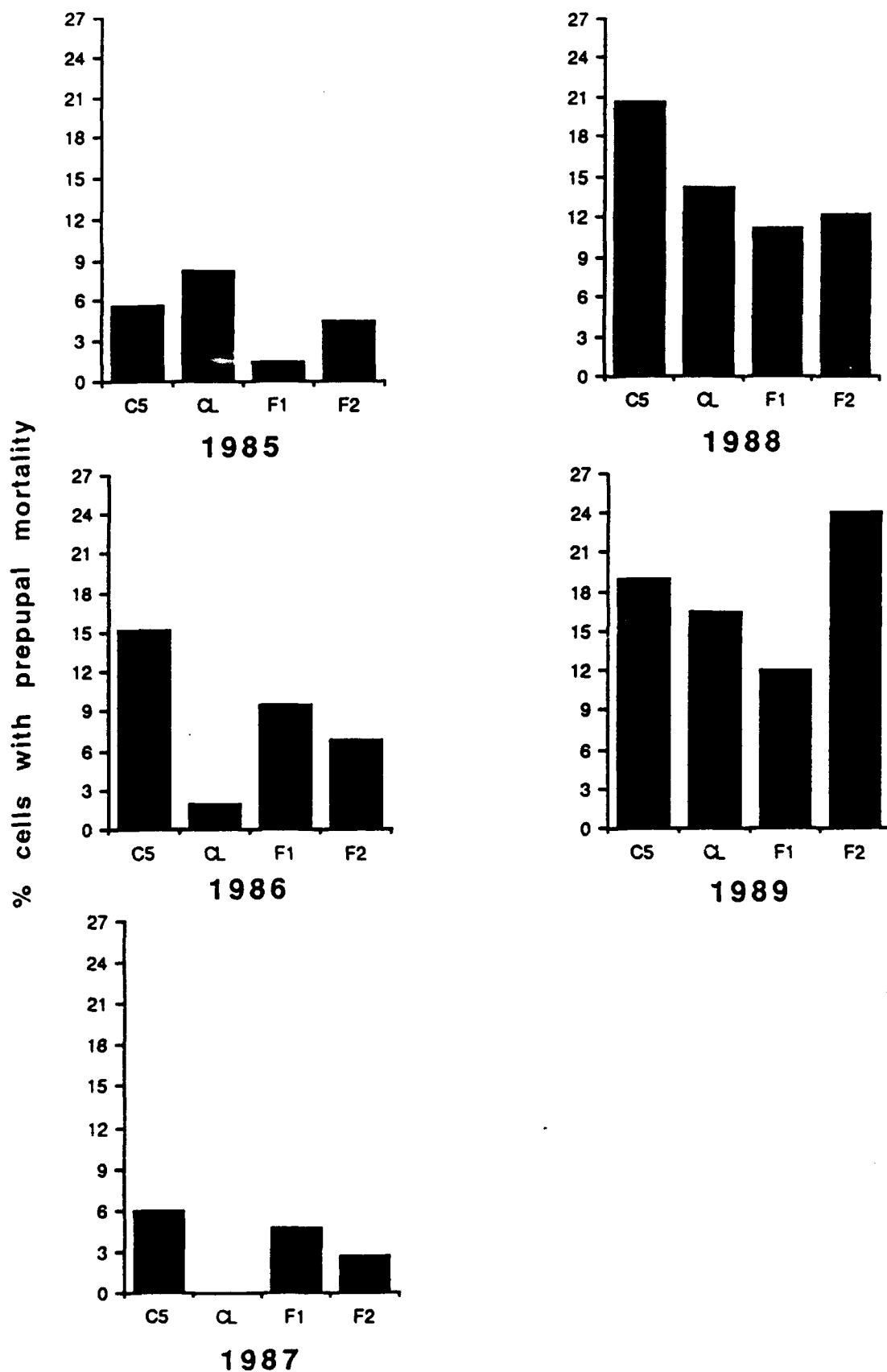


FIGURE 31. Percent of cells with prepupal mortality by year and site, *M. relativa*.

TABLE 35: ANOVA of arcsine transformed proportion of cells with prepupal mortality for M. relativa, 1985 - 1989.

| PROPORTION OF CELLS WITH PREPUPAL MORTALITY |           |              |      |         |
|---|-----------|--------------|------|---------|
| Source of variation                         | df        | SS           | F    | P>F     |
| Year  | 4         | 0.16         | 6.63 | 0.0118* |
| Exp   | 1         | 0.00         | 0.30 | 0.6385  |
| Site[Exp]                                   | 2         | 0.01         | 0.86 | 0.4584  |
| Exp*Year                                    | 4         | 0.02         | 0.99 | 0.5585  |
| Model                                       | 11        | 0.19         | 2.90 | 0.0707  |
| Error                                       | 8         | 0.04         |      |         |
| $\bar{X} = 0.33$                            | CV = 23.4 | $r^2 = 0.80$ |      |         |

TABLE 36: Multiple comparison tests for differences between years in the proportion of cells with prepupal mortality for M. relativa 1985-1989.

| TUKEY GROUPING |   | MEAN    | N | YEAR |
|----------------|---|---------|---|------|
| A              |   | 0.43982 | 4 | 1988 |
| A              |   | 0.43090 | 4 | 1989 |
| B              | A | 0.28535 | 4 | 1986 |
| B              | A | 0.27223 | 4 | 1987 |
| B              |   | 0.22051 | 4 | 1985 |

Experimentwise error rate  $\alpha = 0.05$  df=8

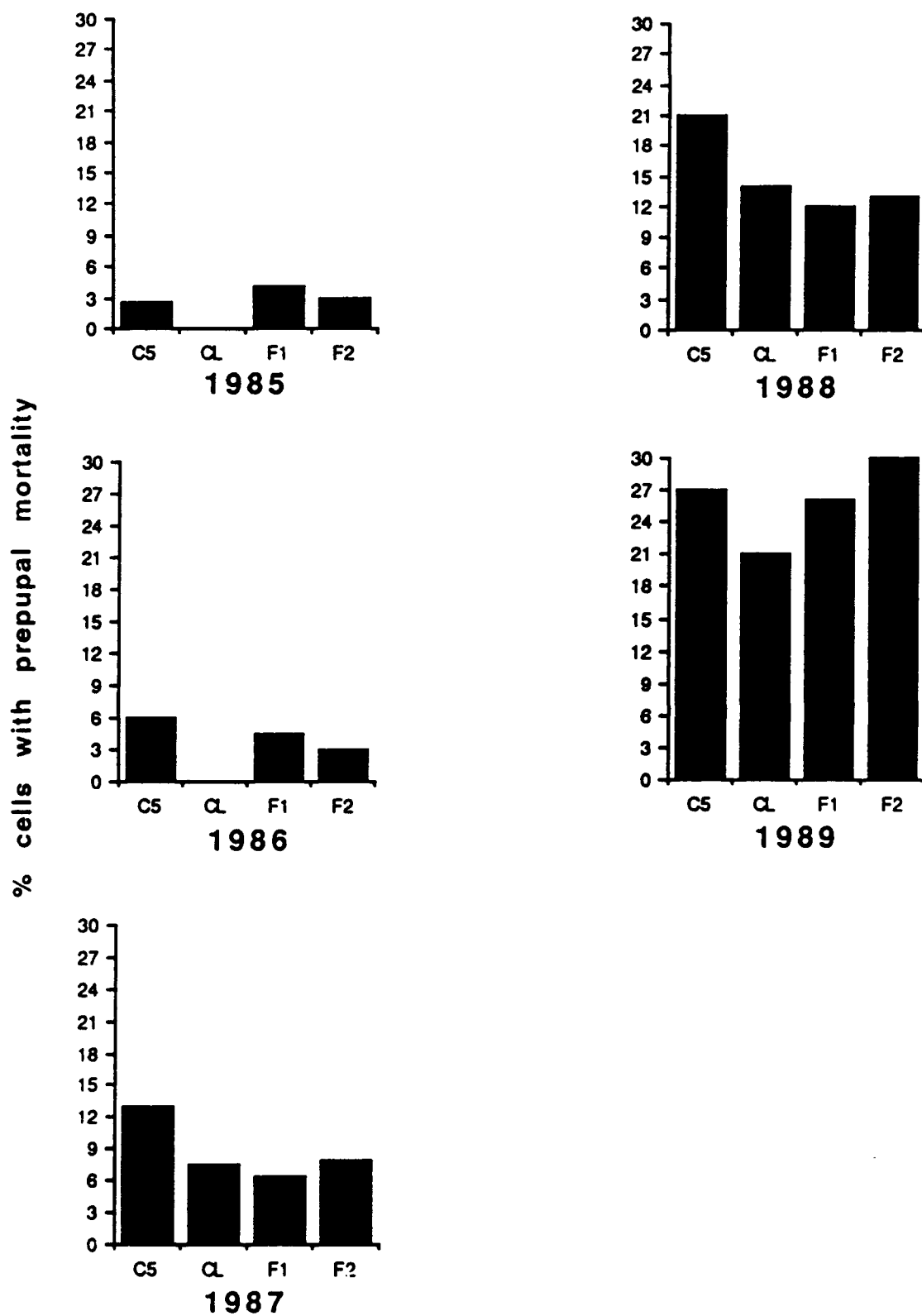


FIGURE 32. Percent of cells with prepupal mortality by year and site, *M. inermis*.

TABLE 37: ANOVA of arcsine transformed proportion of cells with prepupal mortality for M. inermis, 1985 - 1989.

PROPORTION OF CELLS WITH PREPUPAL MORTALITY

| Source of variation                      | df | SS   | F      | P>F       |
|--|----|------|--------|-----------|
| Year                                     | 4  | 0.37 | 180.02 | 0.0001*** |
| Exp                                      | 1  | 0.00 | 0.10   | 0.7870    |
| Site[Exp]                                | 2  | 0.02 | 16.65  | 0.0014*   |
| Exp*Year                                 | 4  | 0.02 | 0.46   | 0.7681    |
| Model                                    | 11 | 0.40 | 71.44  | 0.0001*** |
| Error                                    | 8  | 0.00 |        |           |
| $\bar{X} = 0.32$ $CV = 7.1$ $r^2 = 0.99$ |    |      |        |           |

TABLE 38: Multiple comparison tests for differences between years in the proportion of cells with prepupal mortality for M. inermis 1985-1989.

| TUKEY<br>GROUPING | MEAN    | N | YEAR |
|-------------------|---------|---|------|
| A                 | 0.53585 | 4 | 1989 |
| B                 | 0.39888 | 4 | 1988 |
| C                 | 0.30403 | 4 | 1987 |
| D                 | 0.20869 | 4 | 1986 |
| D                 | 0.15548 | 4 | 1985 |

Experimentwise error rate  $\alpha = 0.05$        $df=6$

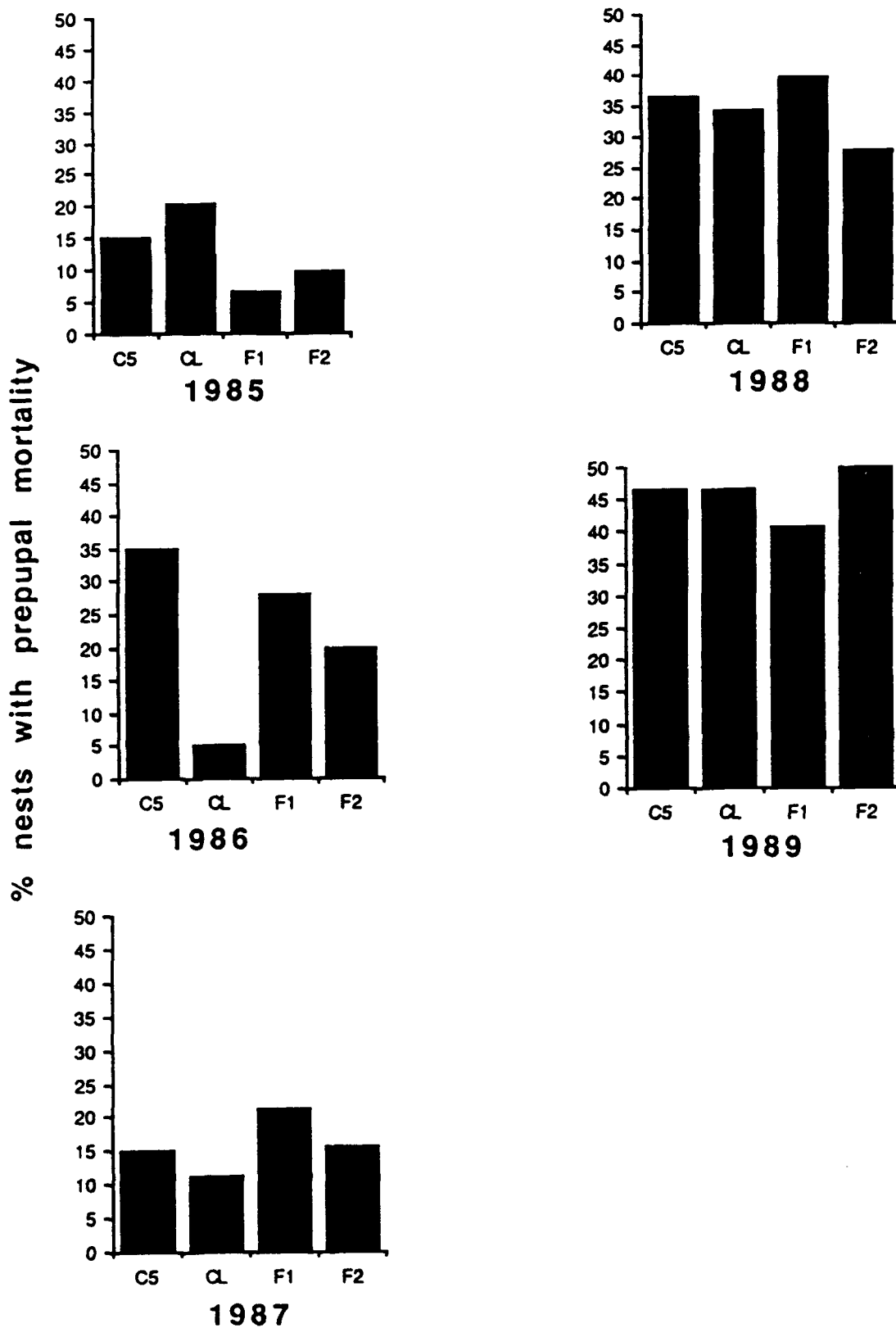


FIGURE 33. Percent nests with prepupal mortality by year and site, M. relativa.



TABLE 39: ANOVA of arcsine transformed proportion nests with prepupal mortality for M. relativa, 1985 - 1989.

PROPORTION OF NESTS WITH PREPUPAL MORTALITY

| Source of variation                       | df | SS   | F     | P>F     |
|---|----|------|-------|---------|
| Year                                      | 4  | 0.39 | 10.06 | 0.0033* |
| Exp                                       | 1  | 0.00 | 0.04  | 0.8636  |
| Site[Exp]                                 | 2  | 0.02 | 0.85  | 0.4625  |
| Exp*Year                                  | 4  | 0.03 | 0.95  | 0.5719  |
| Model                                     | 11 | 0.44 | 4.11  | 0.0275  |
| Error                                     | 8  | 0.08 |       |         |
| $\bar{X} = 0.53$ $CV = 18.6$ $r^2 = 0.85$ |    |      |       |         |

TABLE 40: Multiple comparison tests for differences between years in the proportion of nests with prepupal mortality for M. relativa 1985-1989.

| TUKEY GROUPING |   | MEAN    | N | YEAR |
|----------------|---|---------|---|------|
|                | A | 0.74580 | 4 | 1989 |
| B              | A | 0.63172 | 4 | 1988 |
| B              | C | 0.48123 | 4 | 1986 |
| B              | C | 0.41690 | 4 | 1987 |
|                | C | 0.36938 | 4 | 1985 |

Experimentwise error rate  $\alpha = 0.05$        $df=8$

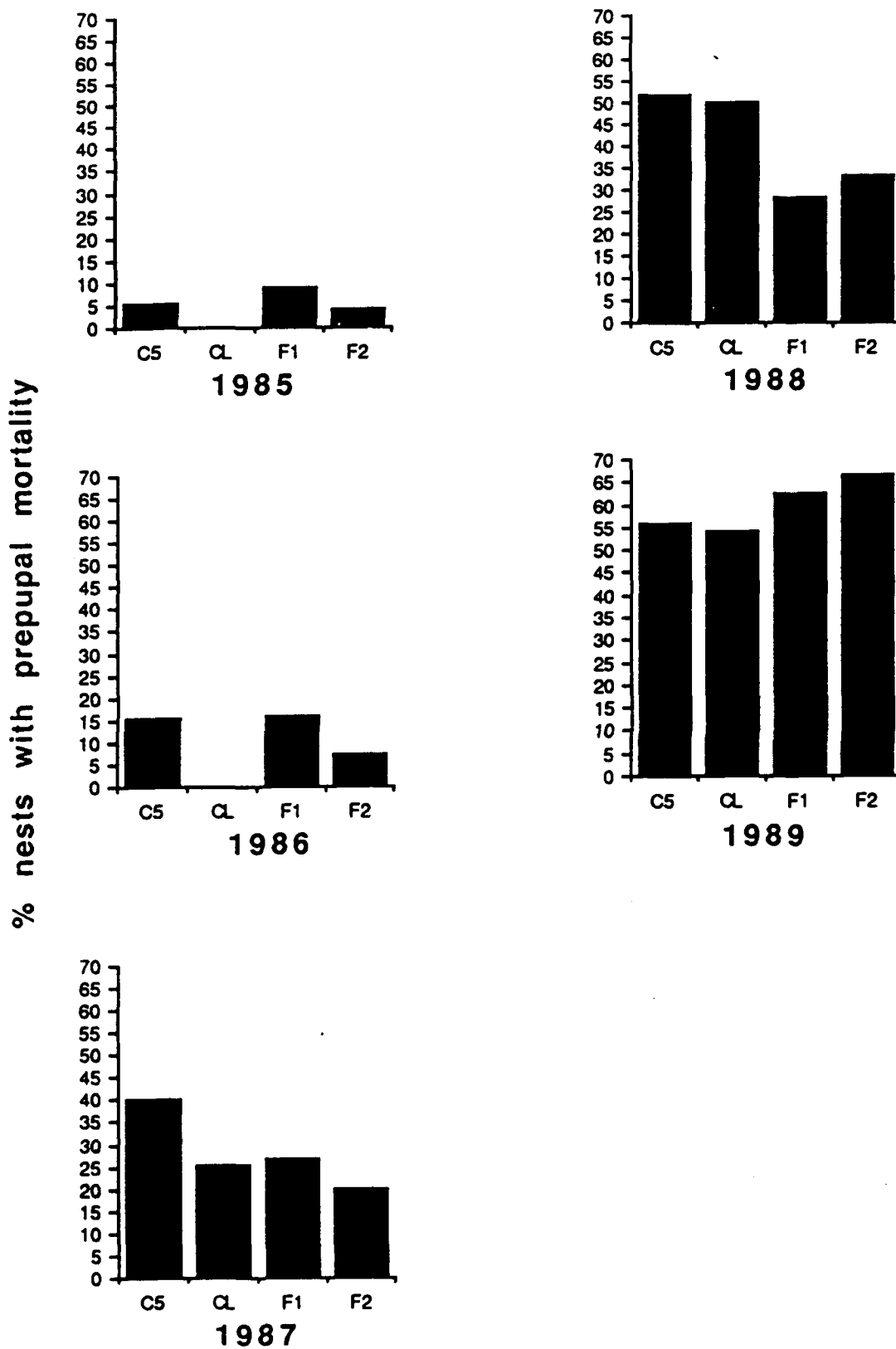


FIGURE 34. Percent nests with prepupal mortality by year and site, *M. inermis*.

TABLE 41: ANOVA of arcsine transformed proportion nests with prepupal mortality for M. inermis, 1985 - 1989.

PROPORTION OF NESTS WITH PREPUPAL MORTALITY

| Source of variation | df       | SS           | F     | P>F       |
|---------------------|----------|--------------|-------|-----------|
| Year                | 4        | 1.07         | 94.75 | 0.0001*** |
| Exp                 | 1        | 0.01         | 0.64  | 0.5078    |
| Site[Exp]           | 2        | 0.07         | 4.09  | 0.0597    |
| Exp*Year            | 4        | 0.06         | 1.29  | 0.4811    |
| Model               | 11       | 1.16         | 37.35 | 0.0001*** |
| Error               | 8        | 0.02         |       |           |
| $\bar{X} = 0.55$    | CV = 9.7 | $r^2 = 0.98$ |       |           |

TABLE 42: Multiple comparison tests for differences between years in the proportion of nests with prepupal mortality for M. inermis 1985-1989.

| TUKEY GROUPING | MEAN    | N | YEAR |
|----------------|---------|---|------|
| A              | 0.88541 | 4 | 1989 |
| B              | 0.69080 | 4 | 1988 |
| B              | 0.56145 | 4 | 1987 |
| C              | 0.35096 | 4 | 1986 |
| C              | 0.24145 | 4 | 1985 |

Experimentwise error rate  $\alpha = 0.05$  df=8

probably due to spring mortality, and may be masking mortality due to ELF EM fields.

Year was significant for both species, with 1989 differing from 1985, and 1985-1987 not being significantly different for M. relativa (Tables 36, 40). For M. inermis (Tables 38, 42), 1985 and 1986 differed from 1987 and all three differed from 1989.

Nests constructed in 1988 were the first to overwinter in the same orientation as they were constructed. We analyzed 1988 and 1989 prepupal mortality by cells and nests, adding the additional variable "direction", indicating whether the nest overwintered along a north-south axis, or along an east-west axis. (It is not necessary to separate nests by hutch set, as in our analysis of acceptability of nest orientations, because nests from all hutch sets

at a site were overwintered in the same box.) We are curious to determine whether direction of the nest contributes significantly to prepupal mortality, particularly at the experimental sites where nests are exposed to ELF magnetic fields that might differentially affect prepupae oriented in particular directions (see Introduction, p. 9). Thus, we are looking for a significant effect of Direction\*Exp.

Analysis of 1988 M. inermis cells suggested that mortality was high at control sites but low at experimental sites for NS oriented nests (1989 Annual Report). However, this pattern was not repeated with either 1989 cells or nests (Tables 43 - 46; Figs. 35 - 38). Analysis of nests with prepupal mortality for M. inermis suggests that mortality at the experimental sites was significantly higher than at control sites in 1989, but not in 1988. This may be an effect of the ELF EM fields, but more likely it is related to high spring mortality at the holding site.

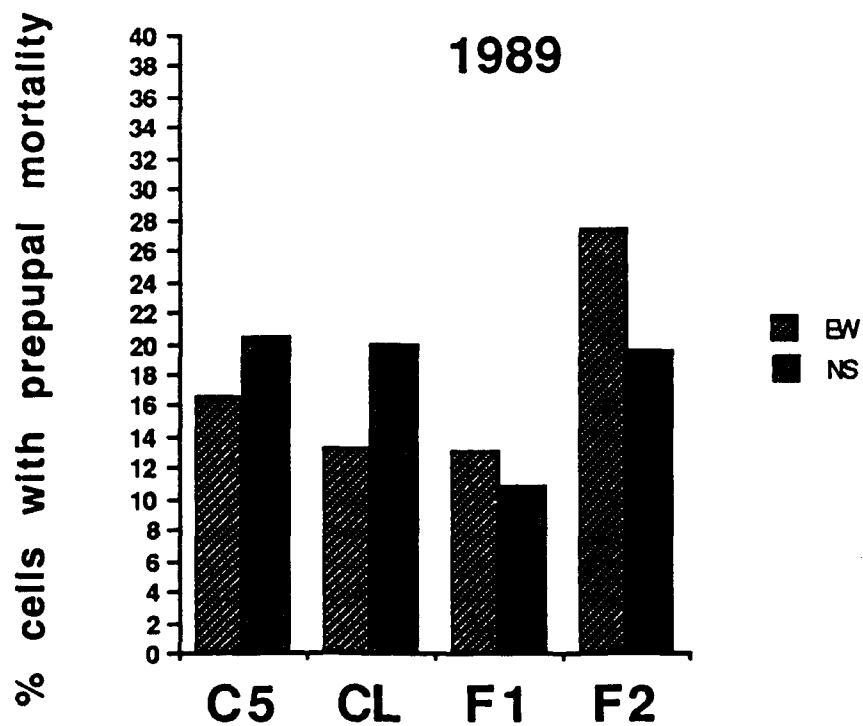
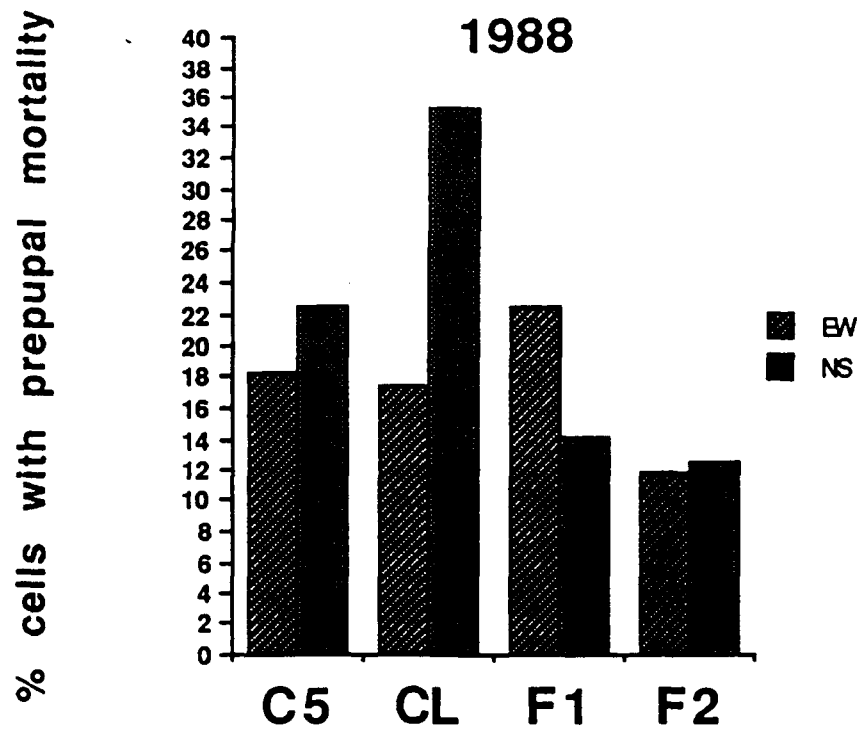


FIGURE 35. Percent of cells with prepupal mortality by year, site, and nest entrance orientation, *M. relativa*.

TABLE 43: ANOVA of arcsine transformed proportion of cells with prepupal mortality for M. relativa, 1988 & 1989.

PROPORTION OF CELLS WITH PREPUPAL MORTALITY

| Source of variation | df        | SS           | F     | P>F    |
|---------------------|-----------|--------------|-------|--------|
| Year                | 1         | 0.00         | 0.34  | 0.5828 |
| Exp                 | 1         | 0.01         | 4.49  | 0.1683 |
| Site[Exp]           | 2         | 0.00         | 0.34  | 0.7257 |
| Direction           | 1         | 0.00         | 0.23  | 0.6474 |
| Direction*Exp       | 1         | 0.03         | 12.74 | 0.0003 |
| Year*Exp            | 1         | 0.01         | 4.46  | 0.1690 |
| Year*Exp*Direction  | 1         | 0.00         | 0.32  | 0.6362 |
| Model               | 9         | 0.05         | 0.99  | 0.5269 |
| Error               | 6         | 0.04         |       |        |
| $\bar{X} = 0.45$    | CV = 17.4 | $r^2 = 0.60$ |       |        |

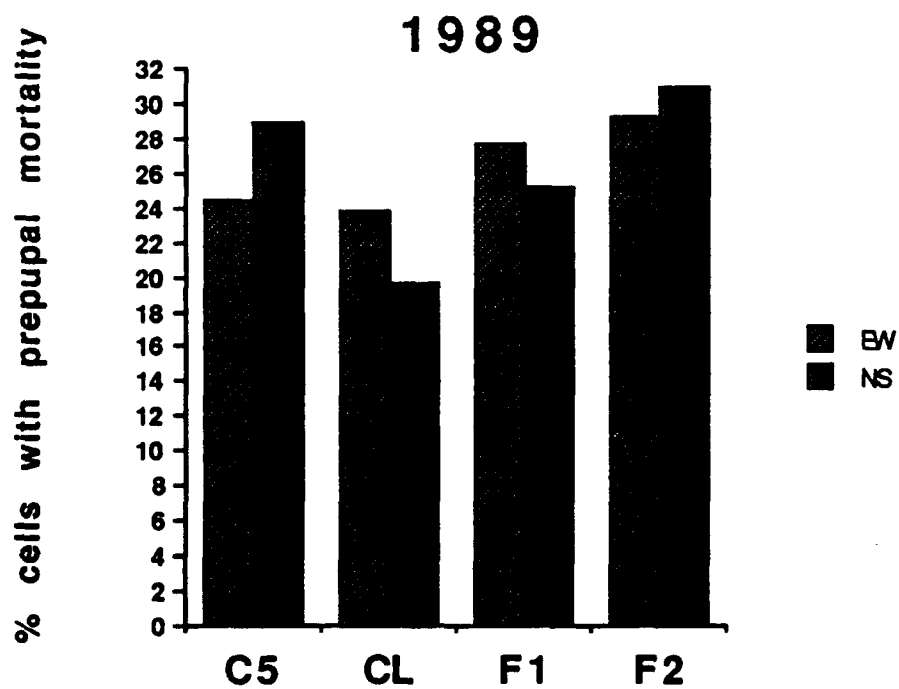
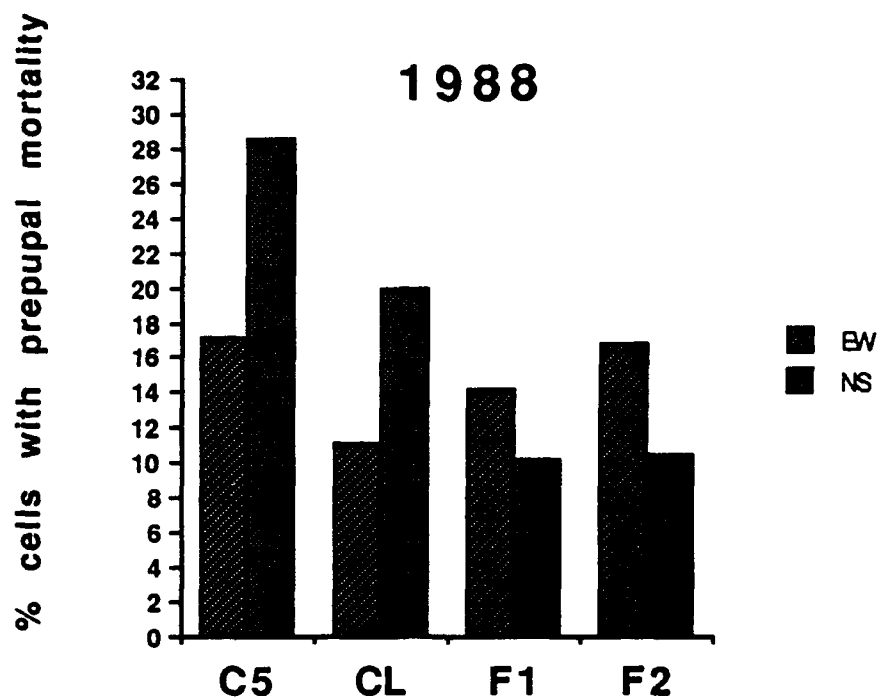


FIGURE 36. Percent cells with prepupal mortality by year, site, and nest entrance orientation, *M. inermis*.

TABLE 44: ANOVA of arcsine transformed proportion of cells with prepupal mortality for M. inermis, 1988-1989.

PROPORTION OF CELLS WITH PREPUPAL MORTALITY

| Source of variation | df       | SS           | F     | P>F       |
|---------------------|----------|--------------|-------|-----------|
| Year                | 1        | 0.05         | 80.61 | 0.0001*** |
| Exp                 | 1        | 0.00         | 1.41  | 0.3575    |
| Site[Exp]           | 2        | 0.01         | 4.81  | 0.0566    |
| Direction           | 1        | 0.00         | 0.62  | 0.4601    |
| Direction*Exp       | 1        | 0.01         | 3.69  | 0.1948    |
| Year*Exp            | 1        | 0.02         | 7.03  | 0.1176    |
| Year*Exp*Direction  | 1        | 0.01         | 3.63  | 0.1969    |
| Model               | 9        | 0.11         | 18.67 | 0.0010**  |
| Error               | 6        | 0.00         |       |           |
| $\bar{X} = 0.48$    | CV = 5.3 | $r^2 = 0.97$ |       |           |



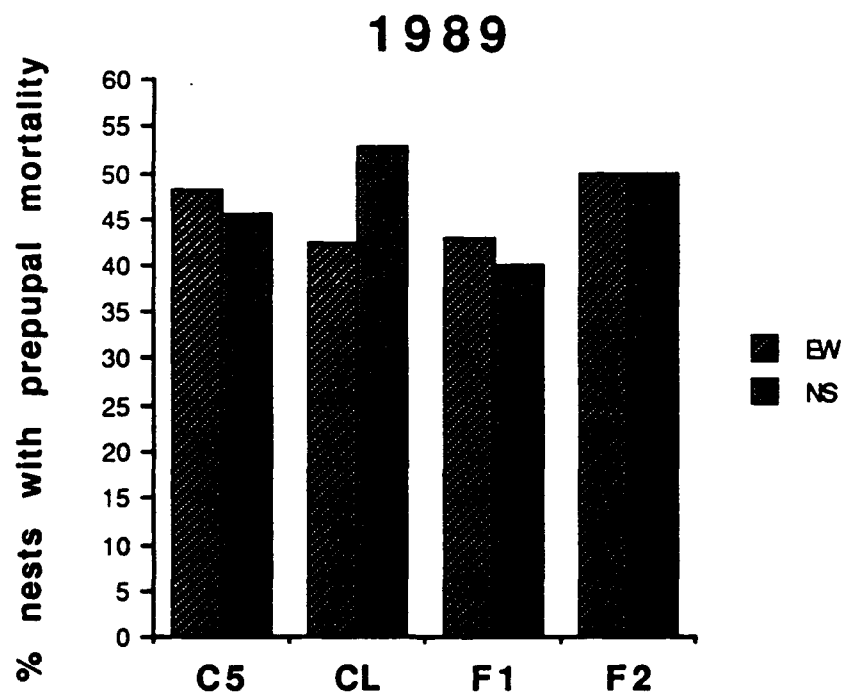
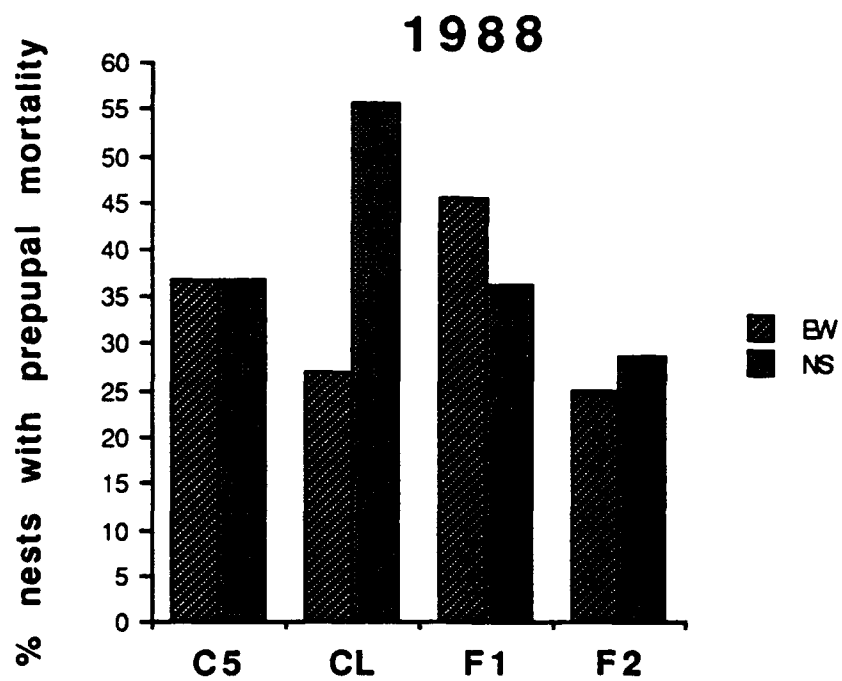


FIGURE 37. Percent nests with prepupal mortality by year, site, and nest entrance orientation, *M. relativa*.

TABLE 45: ANOVA of arcsine transformed proportion of nests with prepupal mortality for M. relativa, 1988-1989.

PROPORTION OF NESTS WITH PREPUPAL MORTALITY

| Source of variation | df        | SS           | F     | P>F    |
|---------------------|-----------|--------------|-------|--------|
| Year                | 1         | 0.04         | 4.73  | 0.0726 |
| Exp                 | 1         | 0.00         | 2.75  | 0.2392 |
| Site[Exp]           | 2         | 0.00         | 0.15  | 0.8653 |
| Direction           | 1         | 0.00         | 0.47  | 0.5187 |
| Direction*Exp       | 1         | 0.01         | 10.76 | 0.0817 |
| Year*Exp            | 1         | 0.01         | 0.86  | 0.4509 |
| Year*ExpP*Direction | 1         | 0.00         | 2.98  | 0.2264 |
| Model               | 6         | 0.07         | 0.92  | 0.5635 |
| Error               | 2         | 0.05         |       |        |
| $\bar{X} = 0.70$    | CV = 13.0 | $r^2 = 0.58$ |       |        |

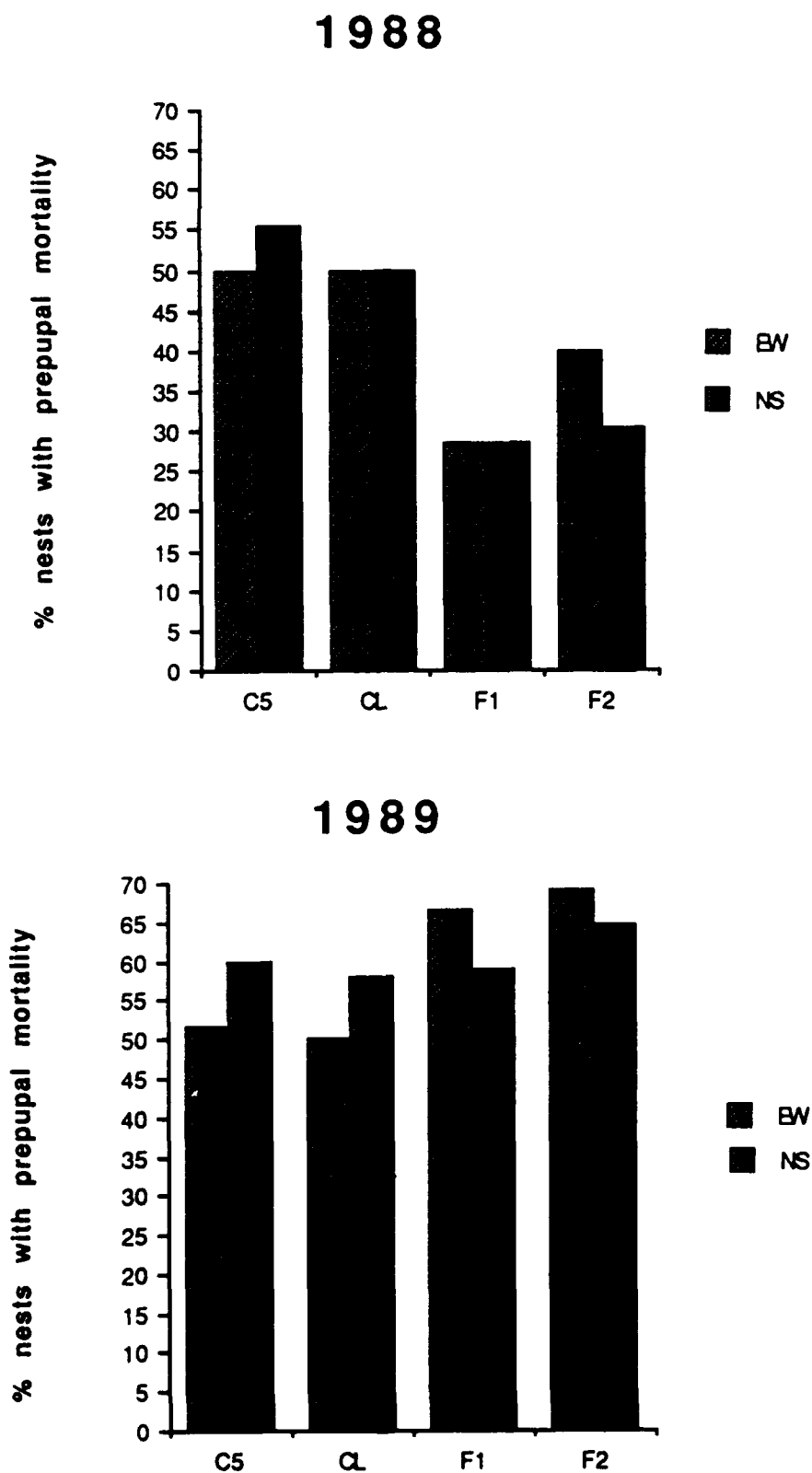


FIGURE 38. Percent nests with prepupal mortality by year, site, and nest entrance orientation, *M. inermis*.

TABLE 46: ANOVA of arcsine transformed proportion of nests with prepupal mortality for M. inermis, 1988-1989.

PROPORTION OF NESTS WITH PREPUPAL MORTALITY

| Source of variation | df       | SS           | F      | P>F       |
|---------------------|----------|--------------|--------|-----------|
| Year                | 1        | 0.14         | 234.75 | 0.0001*** |
| Exp                 | 1        | 0.01         | 3.01   | 0.2249    |
| Site[Exp]           | 2        | 0.01         | 5.43   | 0.0450*   |
| Direction           | 1        | 0.00         | 0.10   | 0.7583    |
| Direction*Exp       | 1        | 0.01         | 3.98   | 0.1840    |
| Year*Exp            | 1        | 0.09         | 29.19  | 0.0326*   |
| Year*Exp*Direction  | 1        | 0.00         | 0.44   | 0.5762    |
| Model               | 9        | 0.26         | 49.46  | 0.0001    |
| Error               | 6        | 0.00         |        |           |
| $\bar{X} = 0.79$    | CV = 3.0 | $r^2 = 0.99$ |        |           |

## VII SUMMARY

Studies of the effects of high voltage transmission lines and magnetic fields in honeybees suggest several ways that solitary megachilid bees might be affected by ELF electromagnetic fields. In particular, honeybees show greater levels of activity, reduced reproductive output, lower overwintering survival and modifications of nest structure in response to high voltage transmission lines. In addition, honeybees can detect magnetic fields and may use them in orientation. ELF EM fields may affect megachilid bees in similar ways.

Megachilid bees are particularly well suited for this study. Their investment per offspring and reproductive output per nest are easy to measure because they provide each offspring with a discrete cell, and because they readily nest in artificial nests. Three types of data have been gathered in past years: nest architecture, nest activity, and emergence/mortality.

Two abundant species at the experimental and control sites, both in the genus Megachile, are the focus of our analysis. These species differ in size and degree of sexual dimorphism. Thus, they may be impacted differently by ELF EM fields.

Four hypotheses regarding the impact of ELF EM fields on nest architecture are being tested:

Hypothesis 1: The average length of cells for each offspring, and/or the average number of cells produced per nest is unchanged by exposure to ELF electromagnetic fields.

Hypothesis 2. Bees exposed to ELF EM fields, and bees not exposed, will make nest plugs of the same thickness and will devote the same proportion of nest space to reproduction.

Hypothesis 3. The number of leaves used to line a cell is unchanged by exposure to ELF EM fields.

Hypothesis 4. The relative acceptability of nests oriented in a NS direction vs. nests oriented in an EW direction does not change when bees are exposed to ELF EM fields.

Nest architecture data for both M. relativa and M. inermis nests constructed in 1985-1989 have been analyzed. Cells expected to have female offspring were larger than cells expected to have male offspring. Mean cell lengths were significantly larger at the CL site, in complete nests, in early season nests, and in nests with few cells. However, there did not

appear to be any effect of ELF EM fields at 50% power (1988) or 100% power (1989) on cell length for either species.

Number of cells per nest was significantly less for nests begun late in the season as compared with those begun early in the season. The distribution of numbers of cells per nest varied between years, sites, and treatment areas, but neither species showed any obvious changes at the experimental sites in 1989 when the antenna was tested at full power.

Mean number of leaves per cell was smaller for female M. inermis cells than for male cells. Nests begun in early season had fewer leaves per cell than did nests constructed late season. For male cells there were differences between sites, and between complete and incomplete nests as well. However, there did not appear to be any effect of ELF EM fields at 50% power (1988) or 100% power (1989) on mean leaves per cell for this species.

Nest entrance orientation was highly variable for M. relativa between hutch sets at a given site, between sites, and between experimental and control areas. Because of this heterogeneity, the data are not likely to be useful for detecting effects of ELF EM fields.

We have not yet analyzed the data to test hypotheses 2.

One hypothesis regarding nest activity is being tested:

Hypothesis 5. The duration of round leaf (LO) foraging trips remains the same when bees are exposed to ELF EM fields.

There were significant differences between years and between sites in the duration of LO collecting trips, however, there were no significant changes in LO durations at the experimental areas after the antenna became fully operational in 1989. Thus, ELF EM fields, even at full power, have not yet had any affect on LO trip durations.

One hypothesis concerning emergence and mortality data has been tested:

Hypothesis 6. Overwintering survival of megachilid bees is unchanged by exposure to ELF fields.

Overwintering mortality takes place when the bee is in the prepupal stage. Because of the effects of microhabitat and year on pre-overwintering (larval) mortality, it was decided to eliminate cells with this mortality from our analysis. Thus our hypothesis has been restated as: Given that a bee survives to the prepupal stage, the probability that it will not survive

past the prepupal stage does not change in the presence of ELF EM fields. We calculate proportion of mortality in the prepupal stage as the number of cells with a dead prepupa divided by the sum of cells with prepupae, pupae, dead adult, or emerging adult bees. Mortality of the parasitic cuckoo bee, Coelioxys, is included in the analysis, since we cannot distinguish the two bee species until the pupal stage.

Although prepupal mortality has been significantly higher in 1988 and 1989 than in previous years for both species, these changes appear to be related to changes in protocol and climate and do not appear to be related to ELF EM fields. Last year we noted that when 1988 M. inermis nests were separated by orientation, NS oriented nests had significantly lower mortality at experimental sites than at control sites. This pattern was not repeated in 1989, however, suggesting that the 1988 pattern was not related to ELF EM fields. However, high prepupal mortality due to cold spring temperatures may be masking effects of ELF EM fields during the winter.





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ELF COMMUNICATION SYSTEM ECOLOGICAL MONITORING PROGRAM

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# TABLE OF CONTENTS

|   |      |
|---|------|
| LIST OF TABLES . . . . .  | vii  |
| LIST OF FIGURES AND PLATES . . . . .  | x    |
| ABSTRACT . . . . .  | xi   |
| SUMMARY FOR LAY AUDIENCE . . . . .  | xiii |
| PREFACE . . . . .   | 1    |
| RATIONALE OF STUDIES . . . . .  | 2    |
| Behavioral Studies . . . . .  | 3    |
| Reproduction, Growth, and Development . . . . .   | 4    |
| Maximal Aerobic Metabolism . . . . .  | 6    |
| OVERALL RESEARCH DESIGN AND SUPPORT FACILITIES . . . . .  | 8    |
| Modifications in Project Scope and Statistical Sufficiency . . . . .                                      | 10   |
| Measurements on 60 and 76 Hz fields . . . . .   | 12   |
| Comments on Ambient Monitoring . . . . .  | 16   |
| STUDY OF SMALL MAMMAL COMMUNITIES . . . . .   | 13   |
| I. Purpose . . . . .  | 18   |
| PARENTAL AND NESTLING BEHAVIOR, AND FECUNDITY,<br>GROWTH AND MATURATION STUDIES - TREE SWALLOWS . . . . . | 19   |
| I. Purpose . . . . .  | 19   |
| II. Methods . . . . .   | 19   |
| III. Results - 1990 . . . . .   | 22   |
| PARENTAL AND NESTLING BEHAVIOR, AND FECUNDITY,<br>GROWTH, AND MATURATION STUDIES - DEERMICE . . . . .     | 36   |
| I. Purpose . . . . .  | 36   |
| II. Methods . . . . .   | 36   |
| III. Results - 1990 . . . . .   | 37   |
| HOMING STUDIES - TREE SWALLOWS . . . . .  | 40   |
| I. Purpose . . . . .  | 40   |
| II. Methods . . . . .   | 40   |
| III. Results - 1990 . . . . .   | 41   |
| HOMING STUDIES - SMALL MAMMALS . . . . .  | 44   |
| I. Purpose . . . . .  | 44   |
| II. Methods . . . . .   | 44   |
| III. Results - 1990 . . . . .   | 46   |
| DEVELOPMENTAL STUDIES . . . . .   | 47   |
| I. Purpose . . . . .  | 47   |

|   |    |
|---|----|
| II. Methods . . . . .                           | 48 |
| III. Results - 1990 . . . . .                   | 49 |
| STUDIES OF MAXIMUM AEROBIC METABOLISM . . . . . | 54 |
| I. Purpose . . . . .                            | 54 |
| II. Methods . . . . .                           | 54 |
| III. Results - 1990 . . . . .                   | 59 |
| CONCLUSIONS . . . . .                           | 63 |
| LITERATURE CITED . . . . .                      | 65 |
| APPENDIX A - TABLES AND FIGURES . . . . .       | 77 |

# LIST OF TABLES

|           |  |    |
|-----------|--|----|
| Table 1.  | Test-control plot pairings for the various work elements for small mammals and nesting birds . . . . .   | 79 |
| Table 2.  | Mean values for 60 Hz transverse electric fields (V/m) on control and test plots paired by research activity . . . .   | 80 |
| Table 3.  | Mean values for 60 Hz longitudinal electric fields (mV/m) on test and control plots for years 1983 to 1990 . . . . .   | 81 |
| Table 4.  | Mean values for 60 Hz magnetic fields (Mg) on test and control plots for years 1983 to 1990 . . . . .  | 82 |
| Table 5a. | 60 Hz Transverse electric field intensities (V/m) at the laboratory site where maximal metabolic measures were being taken . . . . .   | 83 |
| Table 5b. | 60 Hz magnetic flux densities (Mg) made at the laboratory where maximal metabolic measures were being made . . . . .   | 84 |
| Table 6.  | Mean values for 76 Hz transverse electric fields (V/m) on test and control plots for years 1986 (4 amperes), 1987 (15 amperes), 1988 (75 amperes), 1989 and 1990 (150 amperes) . . . . . | 85 |
| Table 7.  | Mean values for 76 Hz longitudinal electric fields on test and control plots for years 1986 (4 amperes), 1987 (15 amperes), 1988 (75 amperes), 1989 and 1990 (150 amperes) . . . . .     | 86 |
| Table 8.  | Mean values for 76 Hz magnetic fields (Mg) on test and control plots for years 1986 (4 amperes), 1987 (15 amperes), 1988 (75 amperes), 1989 and 1990 (150 amperes) . . . . .             | 87 |
| Table 9.  | Tree swallow plots, number of boxes, and percent with egg laying activity on test and control sites for 1985 through 1990 . . . . .  | 88 |
| Table 10. | Tree swallow fecundity data for years 1985-1990 . . . . .  | 89 |
| Table 11. | Likelihood to hatch and fledge for tree swallows for 1985 through 1990 . . . . .   | 90 |
| Table 12. | ANOVA for clutch size of tree swallows . . . . .   | 91 |
| Table 13. | ANOVA for hatch success of tree swallows . . . . .   | 91 |
| Table 14. | ANOVA for fledging success of tree swallows . . . . .  | 91 |
| Table 15. | Exposure data and frequency of mortality of EGGS during 1990 calculated using the Mayfield method (Mayfield 1961, 1975) . . . . .  | 92 |
| Table 16. | Exposure data and frequency of mortality of NESTLINGS during 1990 calculated using the Mayfield method (Mayfield 1961, 1975) . . . . .   | 92 |
| Table 17. | Exposure data and frequency of total nest failure for OVERALL NESTS during 1990 calculated using the Mayfield method (Mayfield 1961, 1975) . . . . .                                     | 93 |
| Table 18. | Exposure data and frequency of total nest failure during the INCUBATION PHASE during 1990 calculated using the Mayfield method (Mayfield 1961, 1975) . . . . .                           | 93 |
| Table 19. | Exposure data and frequency of total nest failure during the NESTLING PHASE during 1990 calculated using the Mayfield method (Mayfield 1961, 1975) . . . . .                             | 94 |
| Table 20. | Age in days at landmark events of eye opening and primary feather eruption in 1986 through 1990 . . . . .  | 94 |
| Table 21. | Nested ANOVA for age of eye opening in tree swallows . . . . .   | 95 |

|           |   |     |
|-----------|---|-----|
| Table 22. | Nested ANOVA for primary feather eruption in tree swallows . . . . .  | 96  |
| Table 23. | Detectable differences and power for tree swallow fecundity variables: clutch size, hatch success and fledging success for data combined for 1985-1990 . . . . .    | 97  |
| Table 24. | Detectable differences and power for tree swallow landmark events; eye opening and feather eruption, for years 1986 through 1990 . . . . .                          | 97  |
| Table 25. | Nested ANOVA for weight growth constant for nestling tree swallows . . . . .  | 98  |
| Table 26. | Nested ANOVA for the inflection point of weight increase in tree swallows . . . . .   | 99  |
| Table 27. | Nested ANOVA for the slope from linear regression of weight increase in nestling tree swallows between ages 3 and 11 days . . . . .                                 | 100 |
| Table 28. | Nested ANOVA for the maximum weight attained by nestling tree swallows . . . . .  | 101 |
| Table 29. | Nested ANOVA for the age of maximum weight attained by tree swallow nestlings . . . . .   | 102 |
| Table 30. | Nested ANOVA for tarsus growth constant in tree swallows . . . . .  | 103 |
| Table 31. | Nested ANOVA for the inflection point of tarsus growth in tree swallows . . . . .   | 104 |
| Table 32. | Nested ANOVA for the slope of the linear regression of tarsus growth (between the ages of 3DPH and 11 DPH) in nestling tree swallows . . . . .                      | 105 |
| Table 33. | Nested ANOVA for the maximum length of tarsus attained by nestling tree swallows . . . . .  | 106 |
| Table 34. | Nested ANOVA for the age of maximum length of tarsus attained by tree swallow nestlings . . . . .   | 107 |
| Table 35. | Nested ANOVA for ulna growth constant in tree swallows . . . . .  | 108 |
| Table 36. | Nested ANOVA for the inflection point of ulna growth in tree swallows . . . . .   | 109 |
| Table 37. | Nested ANOVA for the slope of the linear regression of ulna growth (between the ages of 3 DPH and 11 DPH) in nestling tree swallows . . . . .                       | 110 |
| Table 38. | Nested ANOVA for the maximum length of ulna attained by nestling tree swallows . . . . .  | 111 |
| Table 39. | Nested ANOVA for the age of maximum length of ulna attained by tree swallow nestlings . . . . .   | 112 |
| Table 40. | Nested ANOVA for wing growth in tree swallows . . . . .   | 113 |
| Table 41. | Tree swallow growth constants derived from fitted growth curves . . . . .   | 114 |
| Table 42. | Tree swallow inflection points derived from fitted growth curves . . . . .  | 115 |
| Table 43. | The means of the slope of linear regression of growth measures on nestling age . . . . .  | 116 |
| Table 44. | Means of maximum growth values attained by nestlings . . . . .  | 117 |
| Table 45. | The age of maximum growth values for growing nestling tree swallows . . . . .   | 118 |
| Table 46. | Minimum detectable differences of means for growth constants and the minimum percent detectable change in the mean to reach 70% certainty (power) of test . . . . . | 119 |

|           |   |     |
|-----------|---|-----|
| Table 47. | Minimum detectable differences in mean inflection points and the minimum percent detectable change in the mean to reach 70% certainty (power) of test . . . . .   | 120 |
| Table 48. | Minimum detectable differences of means for linear growth rate and the minimum percent detectable change (n parentheses) in the mean to reach a 70% certainty (i.e. power) of test . . . . .                                | 121 |
| Table 49. | Minimum detectable differences of means for maximum attained values and the minimum percent detectable change (n parentheses) in the mean to reach a 70% certainty (i.e. power) of test . . . . .                           | 122 |
| Table 50. | Minimum detectable differences of means for age at attaining the maximum value for variables and the minimum percent detectable change (in parentheses) in the mean to reach a 70% certainty (i.e. power) of test . . . . . | 123 |
| Table 51. | Statistics for growth rate of body mass for young deermice compared by year and plot . . . . .  | 124 |
| Table 52. | Nested ANOVA of deermice growth rates on test (Pirlot Road) and control (Michigamme) sites for years 1986 through 1990 . . . . .  | 124 |
| Table 53. | Minimum detectable differences and power for deermice growth constants for years 1986 - 1990 . . . . .  | 125 |
| Table 54. | Relevant statistics for age of eye-opening and incisor eruption for deermice reared in enclosures from 1985 through 1990 . . . . .  | 125 |
| Table 55. | Nested ANOVA of deermice age of eye opening on test (Pirlot Road) and control (Michigamme) sites for years 1985 through 1990 . . . . .  | 126 |
| Table 56. | Nested ANOVA of deermice incisor eruption on test (Pirlot Road) and control (Michigamme) sites for years 1986 through 1990 . . . . .  | 127 |
| Table 57. | Minimum detectable differences and power for deermice maturation events for years 1986 through 1990 . . . . .   | 128 |
| Table 58. | Numbers of birds used in the tree swallow homing study and likelihood to return following displacement, 1986-1990 . . . . .   | 128 |
| Table 59. | Mean return times of tree swallows in minutes for 1986-1990 field seasons . . . . .   | 129 |
| Table 60. | Analysis of variance comparing tree swallow return times in minutes for 1986-1990 field seasons . . . . .   | 129 |
| Table 61. | Data on tree swallow likelihood to return pooled over all years (1986-1990) for test and control plots . . . . .  | 130 |
| Table 62. | Detectable differences and power for tree swallow homing: return time for years 1986 - 1990 . . . . .   | 130 |
| Table 63. | Results of the small mammal homing studies at Pirlot Road test site and Michigamme control during the antenna operational years of 1989 and 1990 . . . . .  | 131 |
| Table 64. | Frequency of tree swallow abnormalities, 1990 . . . . .   | 131 |
| Table 65. | Chi-square analysis of developmental abnormalities found in early tree swallow embryos collected from test and control sites . . . . .  | 132 |
| Table 66. | Chi-square analysis of developmental abnormalities found in early tree swallow embryos collected from test and control sites . . . . .  | 132 |

|           |  |     |
|-----------|--|-----|
| Table 67. | Calculated volumes of tree swallow eggs collected from<br>test and control plots . . . . .                             | 133 |
| Table 68. | Egg weights and volumes - basic statistics . . . . .   | 133 |
| Table 69. | Nested Analysis of Variance of egg weights for test<br>and control plots and nests within plots . . . . .              | 134 |
| Table 70. | Nested Analysis of Variance of egg volume for test and<br>control plots and eggs within nests . . . . .                | 134 |
| Table 71. | Summary of peak metabolic rates measured on deermice<br>and chickadees in the week following capture in 1990 . . . . . | 135 |
| Table 72. | Summary of major findings by task for 1985-1990 . . . . .  | 136 |

#### LIST OF FIGURES AND PLATES

|           |   |     |
|-----------|---|-----|
| Figure 1. | Location of Test and Control plots in relation to<br>antenna system . . . . . | 139 |
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#### ABSTRACT

The small mammal and nesting bird biological studies in the western Upper Peninsula of Michigan for the year 1990 are reported. Previous years' data include base-line data from 1983-1985, data collected during partial antenna testing from 1986, 1987, 1988 and full operation in 1989 and 1990.

Data on tree swallow fecundity, survival and growth were analyzed across all years. There were no differences among our main control and test plots for mortality during incubation of eggs nor during raising of nestlings. However, other test plots (we have five total) with high amounts of forest habitat edge had higher mortality for eggs, nestlings and entire nests, due primarily to House Wren depredations and not antenna operation. Other variables that did not differ among our two main plots were clutch size, distribution of clutch size, likelihood to hatch, hatch rate, likelihood to fledge, number fledging, age at eye opening and feather eruption. These variables show year effects due to weather but no effect due to the antenna operation. Growth rates of tree swallow nestlings for body mass, leg length (tarsus), arm length (ulna) and wing length showed no consistent differences between test and control plots over the years of study. The age at half of growth showed no difference between test and control plots for these same variables. All growth variables were very different among nests.

Growth rates of young deermice were similar between test and control plots as was incisor eruption. However, eye opening occurred 2.5 days earlier for young at the test plot compared to the control plot. This was not observed in 1989 but in 1988 a similar difference occurred. We can not tell if this difference was due to the operation of the antenna. A significant effect of the mother on her nestling's growth has occurred on time of eye opening and incisor appearance every year.



Tree swallow homing studies showed greater numbers of displaced birds returned to test than control plots in 1990, a pattern seen also in 1987. The time required to return to the plot was also less for test than control birds and overall times were shorter than in previous years.

Small mammal homing studies indicated no difference in frequency of return for chipmunks, but relatively more deermice returned on test than control plots, a finding opposite to 1989.

Developmental abnormalities were not different in number on test and control plots in 1990. A new measure, egg volume, was also not different among plots.

Maximum aerobic metabolism was similar on plots for deermice and chickadees. For chickadees, this is the second year in a row we have not seen a plot effect. In 1988 and earlier years, chickadees from test plots had lower maximal metabolic rates.

#### SUMMARY FOR LAY AUDIENCE

The 1990 report contains results from the biological studies of small mammals and birds from the time period preceding antenna testing (1983 to 1985), the partial antenna testing years of 1986, 1987, 1988, and the full operational strength of 1989 and 1990. While findings must be considered as incomplete until the end of the project in 1992, each year's data is useful in establishing trends in the aspects of small mammal and nesting bird biology at the study sites.

In all years, nesting tree swallows on both test and control plots laid clutches of similar size with a similar likelihood to hatch and fledge on test and control plots. Mortality of eggs, nestlings and nests taken over both stages of nest life have shown higher, lower and no difference on test compared to control plots over the years. Some of our smaller test plots, which have more forested edge, had greater egg mortality in 1990 due to depredation by House Wrens, which prefer forest edge and also aggressively defend nest-boxes in their territories. Growth and maturation (eye opening, feather appearance) of nestling tree swallows showed no difference on test and control plots, with the possible exception of leg growth. This trend continues findings of earlier years. As in previous years, parental care seems to greatly influence nestling growth and parents differ greatly in their ability to raise their young. These differences are obvious on test and control plots. Growth and maturation of deermice showed no difference between test and control plots. As with the tree swallows, mothers showed large differences in their ability to raise their offspring.

Homing studies of tree swallows continued to show higher rates of return and faster return times for birds from test plots. Overall, times to return were shorter on both test and control plots compared to previous years.

Chipmunks use in our homing studies had similar return rates on test and control plots, however, deermice were not as likely to return to test plots as controls, a reversal of the finding for 1989.

Abnormalities of tree swallow embryos showed no difference in frequency between test and control plots. A new measure was used this year to compare eggs, a volume measure. No difference between test and control plots was found for this measure.

Maximal metabolism of deermice and chickadees showed no difference for test and control plots. This is the first year that chickadees have not shown a plot effect (lower on test plots).

## **SMALL MAMMALS AND NESTING BIRDS 1990 ANNUAL REPORT**

### **PREFACE**

This report begins with an extensive statement of the rationale for the studies proposed (see next section, titled "Rationale for Proposed Studies"). Then a section is provided on the overall research design and research facilities. Individual elements of the work are then described in detail in a series of subsequent sections. Each of the sections on individual work elements consists of three parts: (1) a brief restatement of the purpose (rationale) for the work, (2) a detailed description of research methods, and (3) a presentation of representative results gathered during prior years. The presentations of results include discussions of statistical sufficiency, including projections of the sample sizes required to discriminate between test and control plots in future years.

## SMALL MAMMALS AND NESTING BIRDS 1990 ANNUAL REPORT

### RATIONALE OF STUDIES

Dozens of species of small birds and mammals are resident near the ELF Communication System, in the upper peninsula of Michigan, and the operation of the Communication System could in principle affect any of them in any of countless ways. Even with virtually unlimited resources, it would be impossible to monitor individually all ecologically important aspects of all species for possible effects of the Communication System. Accordingly, we have had to exercise informed judgment in selecting variables for study. In this process, we have been guided by one overriding goal.

Our major goal has been to focus much of our effort on attributes of individual animals that are particularly likely to be susceptible to perturbation by the ELF Communication System. The reason for this focus is that laboratory research indicates that if the ELF Communication System is to have effects on birds or mammals, the effects will likely be small, and thus a statistically robust experimental design will be required to detect them (AIBS 1985). Large numbers of independent measures can be readily obtained on individual attributes, thus facilitating statistical detection of even small effects that the ELF Communication System might have.

In our studies of attributes of individual birds and mammals, we emphasize ecologically significant variables that are especially likely to be susceptible to perturbation. Reproduction and development, for example, receive particular attention because they not only are demographically important but also are more likely to be sensitive to adverse environmental changes than many other animal properties (e.g., Goodposture 1955, Koskimes 1950, Kluijver 1951, Krebs 1971, Lack 1954, 1966, Nice 1954, Perrins 1965,

## SMALL MAMMALS AND NESTING BIRDS 1990 ANNUAL REPORT

Perry and Rowlands 1973). Behavior is studied in depth because it is sometimes modified readily and such modifications can have major repercussions on the lives of individuals and populations (e.g., Cohen et al. 1980, Green 1979, Morse 1980, O'Connor 1978, Slobodkin 1968).

In the following paragraphs we describe in detail the rationale for each aspect of our work on individual attributes. This work is concentrated on four particularly abundant species. The species have been carefully selected with a view to maximizing their ecological and taxonomic diversity, so as to maximize the probability of detecting whatever diverse effects the ELF Communication System may have. The four are the tree swallow (Tachycineta bicolor), the woodland deer mouse (Peromyscus maniculatus gracilis), the black-capped chickadee (Parus atricapillus) and the eastern chipmunk (Tamias striatus). To facilitate readability in the remainder of the report, they will be referred to simply as the "tree swallow", "deer mouse", "chickadee" and "chipmunk", respectively.

### Behavioral Studies

In view of the established sensitivity of certain types of orientational behavior to alteration by the ELF fields (e.g., Graue 1974, Keeton et al. 1974, Larkin and Sutherland 1977, Southern 1969, 1971, 1972a, 1972b, 1973, 1974, 1975, 1976), orientation and homing in the tree swallow, deer mouse, chipmunk, and certain other mammals are being tested to see if they are affected by the ELF Communication System. Specifically, the ability of animals to return to their home-range or territory after displacement is being assessed. We know that animals are able to find food (Krebs 1971, Royama 1966) and escape predators (Metzgar 1967, Watson 1964) more effectively in their home-range or territory than in less familiar areas. Thus, any

## SMALL MAMMALS AND NESTING BIRDS 1990 ANNUAL REPORT

disturbance of their ability to return to their home-range or territory after wandering afar could decrease their probability of survival.

The attentive behavior of parental tree swallows and deermice is being assessed by monitoring visits to the nest containing eggs and young. Disturbance of attentive behavior by the ELF Communication System, if it occurred, could impair development of eggs or nestlings inasmuch as the latter are dependent on parents for both food and warmth (e.g., Balen and Cove 1972, Hill 1972b).

### Reproduction, Growth, and Development

The frequency and type of prenatal developmental abnormalities are examined in tree swallows. Mammals are not studied in this respect because reproductive females would have to be killed to examine fetuses, and such deaths could have serious, adverse effects on population demographics. Prenatal developmental stages are especially likely to be susceptible to perturbation (Axelsson 1954). Developing avian embryos have two major periods of sensitivity (Hamilton 1952) which occur during the first 4 days following the onset of incubation and the period just prior to hatching. A majority of the spontaneously occurring developmental abnormalities manifest themselves during these two periods (Riddle 1930, Hutt and Pilkey 1930, Hutt and Greenwood 1929, Hutt and Crew 1929, Landauer 1943, Martin and Insko 1935, Hamilton 1952). During these periods, the embryos are sensitive to changes in naturally occurring environmental agents such as temperature, humidity, CO<sub>2</sub>, and O<sub>2</sub> (Alsop 1918, Babott 1937, Pembrey et al. 1894, Romanoff et al. 1938, Taylor et al. 1933). Additional teratological agents include vitamins and their antagonists (Cravens 1952), hormones (Zwilling 1956), alcohol and ether (Stockard 1914), metal ions (Ridgeway and Karnofsky 1952), narcotics (Reese

## SMALL MAMMALS AND NESTING BIRDS 1990 ANNUAL REPORT

1912), various forms of radiation (Windle 1893, 1895, Gilman and Baetjer 1904, Hinrichs 1927, and Dixon 1952) and physical jarring (Stiles and Watterson 1937). Since the onset of this investigation, effects of ELF radiation on chick development have been reported (Delgado et al. 1982, Ubeda et al. 1983, Juutilainen and Sali 1986, Juutilainen et al. 1986). There is, at present, no evidence to demonstrate that electric and magnetic fields of the magnitude generated by the ELF Communication System are capable of directly causing embryonic or fetal developmental defects. However, indirect effects are possible. Should the incubation behavior of parent birds be disturbed by the ELF Communication System, developing eggs might suffer developmental abnormalities by virtue of experiencing abnormal reductions or fluctuations in temperature. (Zwilling 1956, Hamilton 1965).

We monitor aspects of fecundity in both tree swallows and deermice. In the birds, we count the number of eggs produced per female and the number of viable eggs and young per clutch. In the mice we monitor numbers of young per litter. Fecundity is an important variable to study not only because it is demographically significant but also because it reflects on a number of variables that could, in principle, be affected by the ELF Communication System. Alteration of male or female reproductive physiology could affect fecundity. Further, any serious disturbances of prenatal development in mammals or birds would likely be reflected in a decrease in fecundity inasmuch as abnormal embryos frequently fail to be born (i.e., they are resorbed in utero or fail to hatch) or are eaten or discarded by the parents soon after birth.

Postnatal mortality and the growth and development of nestling tree swallows and deermice are also followed. Any effects that the Communication



## SMALL MAMMALS AND NESTING BIRDS 1990 ANNUAL REPORT

System might exert on the young themselves could be reflected in altered rates of mortality, growth, or development. Alternatively, disturbances of parental attentive behavior could be influential because the rates of mortality, growth, and development of nestlings are dependent on the extent to which parents provide food and warmth (Hill 1972b). The size of nestlings at the time of weaning or fledging is of particular interest because when young become independent of their parents, they must become substantially self-sufficient and their maturity can affect their likelihood of survival. Evidence exists that young birds that are of relatively small size at fledging are significantly less likely to survive than ones that grow to larger size while in the nest (Lack 1966, Murphy 1978, Perrins 1965).

### Maximal Aerobic Metabolism

In the region of the ELF Communication System, low temperatures make winter the most physiologically stressful time of year, at least for animals such as chickadees that live wholly or predominantly above the snow. We study physiological variables that affect the ability of chickadees and small mammals to cope with the severity of the winter climate. Deficits in the physiological ability to cope would be expected to decrease the probability of survival to the next reproductive season.

Birds and mammals keep warm in cold environments by producing heat metabolically to offset heat losses. The extent to which they can keep their body temperature above air temperature depends on how rapidly they can produce heat. In other words, the lowest air temperature at which they can maintain their usual body temperature is a function of their maximal rate of aerobic metabolism (= heat production) (Hart 1957). In view of these principles, we measure the maximal rate of aerobic metabolism of chickadees and deermice

## SMALL MAMMALS AND NESTING BIRDS 1990 ANNUAL REPORT

during winter. This peak rate of heat production is informative not only because it determines the lowest air temperature at which thermoregulation is possible but also because it likely provides an index of metabolic endurance. The higher an animal's maximal rate of heat production is, the longer the animal will be able to maintain any particular submaximal rate of heat production (Astrand and Rodahl 1977, Wickler 1980). Endurance is important because low air temperatures demanding high heat production can persist for long periods of time.

Beyond its immediate significance for survival in a cold climate, the maximal rate of aerobic metabolism is a valuable variable to measure because it provides an index of physiological health. In fact, peak aerobic metabolism is widely used as such an index in studies of humans. In their classic Textbook of Work Physiology, Astrand and Rodahl (1977) state that "the maximal oxygen uptake is probably the best laboratory measure of a person's physical fitness" if by fitness we mean the capacity of the individual for prolonged heavy work. Brooks and Fahey (1984), in the best of the recent texts on human exercise physiology, state that the maximal aerobic metabolism is "a good measure of fitness for life in contemporary society". Just as peak aerobic metabolism is used as an index of fitness for humans, it can also be so used in studies of animals. A deficit in the peak metabolism among individuals living near the ELF antenna would indicate that some attribute of the all-important systems involved in oxygen supply and use has been adversely affected by the ELF electromagnetic fields. Additional tests would then be required to determine the particular attribute(s) affected. The ability of the respiratory system to provide oxygen, the ability of the circulatory system to transport oxygen and nutrients to metabolically active tissues, the

## SMALL MAMMALS AND NESTING BIRDS 1990 ANNUAL REPORT

ability of storage tissues (e.g., adipose tissue) to mobilize stored nutrients, and the enzymatic competence of metabolically active tissues to catabolize nutrients are among the variables that influence an animal's peak rate of aerobic metabolism (Wang 1978). In human studies, peak aerobic metabolism is usually elicited by having individuals run on a treadmill. We elicit peaks by exposing animals to cold, in part because the method is technically simpler than treadmill running (given that animals require extensive training to use a treadmill successfully) and in part because the cold-induced peak is of immediate relevance to understanding winter ecology.

### OVERALL RESEARCH DESIGN AND SUPPORT FACILITIES

To detect possible effects of the ELF Communication System, we compare animal attributes on test plots (test sites) with those on paired, spatially separated control plots (control sites).

**Test plots**, as specified in the original IITRI Request for Proposals, are areas close enough to the Communication System that electric and magnetic fields attributable to the System, and measured in the soil near the earth's surface, will approximate 0.07 volt/meter and 0.03 Gauss, respectively. Furthermore, electric and magnetic fields attributable to ELF sources other than the System are to be at least an order of magnitude lower than those attributable to the System.

**Control plots**, according to the original Request for Proposals, are areas sufficiently distant from the Communication System that electric and magnetic fields attributable to the System, measured in the soil near the earth's surface, are at least an order of magnitude, and preferably two orders of magnitude, below those at paired test plots. Furthermore, electric and magnetic fields in the air and earth attributable to ELF sources other than

## SMALL MAMMALS AND NESTING BIRDS 1990 ANNUAL REPORT

the System (especially 60 Hz sources) are not to differ by more than an order of magnitude between the control plots and their paired test plots.

For purposes of experimental design, the test plot(s) used for any particular work element are paired with particular control plot(s). The plots of a pair are matched as closely as possible for vegetation, soil type, drainage, and other such features. By pairing plots in this way, we minimize the likelihood that non-ELF differences between plots will introduce significant confounding effects into our results.

A major strength of our research is the paired plot design. Within a year, we can compare possible ELF effects across plots. The design has an additional strength due to the capability of before and after comparisons for each plot where each plot can be used as its own control through time. We consider three phases of antenna operations: 1) pre-antenna, 1983-1985, 2) antenna testing, 1986-1988, and 3) full antenna operation, 1989-1991.

Different work elements are carried out on different pairs of plots for several reasons. Specific work elements could interfere with other work if both were carried out on the same populations of animals; areas where we artificially remove animals (e.g., bird embryos), for example, are not used for research on natural populations. Another factor that demands the use of different plot pairs for different work elements is that the various species we study do not all occur in similar habitat types; field habitats are required for the swallows, whereas forests are required for the deermice.

To minimize potentially confounding differences between test and control plots, sham corridors have been cut through the forests at the control plots. These corridors are clearings of the same width as the corridors cut for installation of the Communication System antenna near test plots. They were

## SMALL MAMMALS AND NESTING BIRDS 1990 ANNUAL REPORT

cut with similar equipment, and they have been treated similarly after cutting. In brief, the sham corridors are as identical as possible to the antenna corridor except that antenna poles and wires have not been installed in the shams. Areas for animal study on control plots and those for animal study on test plots are located about the same distance from the sham corridors and antenna corridor, respectively.

Plots were established as matched pairs (Table 1) of test and control plots for the various work elements. Test plots were located along the north-south antenna element and control plots were located at varying distances to the west of the antenna (Figure 1). The names given to the plots (Table 1) are the standardized ones we use in all our descriptions of experiments and results. The alpha-numeric codes for plots are those used by IITRI.

### **Modifications in Project Scope and Statistical Sufficiency**

The number of study elements was reduced in March, 1989, when budget cuts were made to meet increased wages of non-faculty employees on the project. The wage increases resulted from a labor settlement at Michigan State University. The following research elements were dropped: small mammal community studies, small mammal parental care, and tree swallow incubation. All remaining research elements were continued at full strength.

We have revised our standards for statistical sufficiency for the research program based on our years of experience with the various study elements to date. We originally established the standard of statistical sufficiency in our work that we predicted would provide a 90% certainty of detecting a 20% difference between test and control sites at the 5% level of significance. While we can still meet these standards on some of our work, we clearly can not for others, such as growth of both tree swallows and deermice

## SMALL MAMMALS AND NESTING BIRDS 1990 ANNUAL REPORT

(see Tables dealing with growth). Variation among nests unrelated to plot is the principle reason. These unexpectedly high variances lead to projections of sample sizes beyond the possible scope of our research. We must therefore relax our standards of statistical sufficiency. We have decided to report the actual level of detectable difference in means achieved in a test and the difference we could detect if we relaxed the level of certainty (power) to 70%. The reader will therefore be able to judge for each test the particular statistical confidence that can be met. Literature values for detectable differences or power are not currently known to us for comparison. It seems that most authors do not report either value. For discontinuous variables, we have used different procedures to determine sample size (see Gill 1978, p. 82). Therefore we do not propose changes in statistical sufficiency since we appear to be able to meet the stricter requirements with these data. Discussion of sample size and power of test are presented with the data for each study element (see below).

Our base of operations for the on-site field and laboratory studies is a large house rented in Crystal Falls, MI (801 Crystal Ave.). The physiology laboratory is installed there. The holding facility for temporary housing of animals used in the physiology experiments is located approximately 3.5 miles south of Crystal Falls, MI in an area with minimal electromagnetic interference. We have a shop for construction and maintenance of field equipment and a large shed for storage of traps, cages, construction materials, and seasonal field equipment. We also have a well established data management system housed there (see below), and living space is provided for employees. We rent and maintain three pick-up trucks to provide transportation between our base of operations and field research sites in all

## SMALL MAMMALS AND NESTING BIRDS 1990 ANNUAL REPORT

weather conditions on a year-round basis. In addition, we rent a snowmobile to gain access to our more remote sites during winter and spring when traveling the entire distance by truck becomes impossible.

For data management we employ an IMS (now LF Technologies) computer system at the MSU Museum in East Lansing. The system is multi-user and allows storage of data on fixed and removable media. Zenith (AT-class) computers are used at the field laboratory in Crystal Falls. Data transfer and analysis are accomplished using both systems. Field data are collected by NEC PC-8201A portable computers. We have developed software to standardize and error check field data as it is recorded. Collected data are transferred directly into an AT computer at the field laboratory each day. Transferred data are immediately edited and stored on removable and fixed disks for later analysis. Certain data are analyzed as soon as they are collected. This data management design allows us to collect and analyze large amounts of data very efficiently and accurately. In addition, in 1987, we added high speed tape backup systems to aid in recovery of data should either computer system fail, and for archiving the now voluminous data sets for the various study elements. The large sample sizes required in many of our study elements necessitate the careful and accurate data handling the system provides.

Other major equipment is described in connection with individual work elements in the sections that follow.

### Measurements on 60 and 76 Hz fields

Engineers provided by IITRI have measured 60 Hz electric and magnetic field intensities every year starting in 1983 on our test and control plots, and all the pairs we now use adequately meet the standards for field intensities already described. Electric and magnetic fields produced by the

## SMALL MAMMALS AND NESTING BIRDS 1990 ANNUAL REPORT

antenna system (76 Hz) were measured starting in 1986, when low amperage testing began. Measurements have continued as the antenna has become operational. A summary of the data 1983-1990 is provided in Tables 2 - 9. Details of the results of the field-intensity measurements and the measurement techniques can be found in Enk and Gauger (1985), Brosh et al. (1985 and 1986), and Haradem et al. (1987, 1988, 1989 and 1991). Earlier discussion of measures and plot pairings are outlined in the 1984 annual report (Beaver et al. 1985, pp. 3-9).

In all years, measures were made in September or October by IITRI personnel on our test and control plots during antenna operation. The distribution of operation hours by month for 1986, 1987 and 1988 for the north-south and east-west antennas were concentrated in the months of June through November in 1986 and 1987. Continuous operation began in 1988, but the antenna was shut down for repairs during most of the months of January, February and March, 1989, during our winter studies. Continuous operation occurred through out the remainder of 1989 and all of 1990 (Haradem and Gauger 1991). During these years, the amperage of antenna operation varied from 3 to 75 amperes. Schedules of research activities in the spring and summer fell within the times of heaviest antenna operation in all years. Operation of the antenna was conducted on a 33% time rotation schedule in which the east-west antenna was on for 5 min, then the north-south antenna for 5 min, followed by both antennas off for 5 min. The percentage of time the MTF was on varied from 1.8% (1986) to nearly 100% (1990). The antenna was off for repair and maintenance for about 5 hours twice per week in 1990 (Haradem and Gauger 1991).



## SMALL MAMMALS AND NESTING BIRDS 1990 ANNUAL REPORT

### 60 Hz Fields - Background measures

Measurement of background 60 Hz fields on control and test plots began in 1983. These fields are produced by existing power lines near the study plots. Plots were chosen to have minimal values for 60 Hz fields and to be matched as control and test plots, within the standard of one order of magnitude. Transverse electric fields were initially at or near the lower limits of measurability on all plots (Table 2). Low power testing of the antenna began in 1986 and continued through 1988 at increasing amperage. Values for transverse electric fields then increased on one test plot (1T2) in 1987, and the all test plots through 1990. Control plots remained unaffected. Apparently the fields produced by near by power lines couple to the antenna and re-radiate as 60 Hz fields (Gauger, personal communication).

Averaged values for longitudinal electric and magnetic 60 Hz fields (Tables 3 and 4) were higher on test compared to control plots in most years. Control test plot ratios varied from about 1 to over 27 fold for longitudinal fields, with the high value coming from 1988 for 1T6 vs 1C4 (Table 3). Longitudinal electric fields averaged highest on control plots in 1984 and on test plots in 1988. Magnetic fields remained relatively constant on controls but increased from 1986 through 1988 and then level off in 1990. On test plots, magnetic fields increased from 1986 to 1988 and then decreased in 1989 and 1990 (Table 4).

Among sites within the control plot, 1C1 and 1C3 (Michigamme North and South) were consistently higher for 60 Hz longitudinal electric fields (Table 3). Test plots 1T5 and 1T6 (Ford River North and South) were higher than other test sites in most years (Table 3). Magnetic fields showed larger values for site 1C6 but no patterns in other control plots. Plots 1T2-1T6 all

## SMALL MAMMALS AND NESTING BIRDS 1990 ANNUAL REPORT

increased in 1986, 1987, and 1988 (Table 4), but then decreased in 1989 and 1990. Site 1T1 showed a smaller increase and then a decrease in these years.

The control release location (1D3) and Panola Plains (1C4) control site for tree swallow homing showed small differences in field strength for electric and magnetic fields (Tables 2-4). However, much larger ratios appeared on test release locations (1D1 and 1D2) and their corresponding test sites (1T2, 1T4) for transverse, longitudinal and magnetic fields (Tables 2-4).

Measurements of 60 Hz fields were also conducted in the laboratory where maximal metabolic scope is done. A number of sites near equipment and in the holding facilities were measured by IITRI personnel. Shielding was provided for animal containers and laboratory locations where animals had direct exposure. The shielding significantly reduced the strength of electric and magnetic fields (Tables 5a,b).

### 76 Hz Fields

In 1986, 1987 and 1988, measurements were made on 76 Hz fields produced by the antenna during testing. Variation of 76 Hz fields was examined among control plots to see if they were homogeneous. Control plots were all uniform with respect to transverse electric (Table 6) and magnetic fields (Table 8). For longitudinal electric fields (Table 7), sites 1C1 and 1C3 were significantly greater than 1C4 and 1C6.

Among test plots, 1T5 was greater than other sites for transverse electric fields (Table 6), and 1T6 was greater than other sites for longitudinal electric fields (Table 7). No other patterns emerged. The control plots 1C1 and 1C3 are closer to the antenna system by several Km, perhaps explaining their higher values. Test site longitudinal electric

## SMALL MAMMALS AND NESTING BIRDS 1990 ANNUAL REPORT

fields differ from each other because of varying distances to the antenna wire and because of variations in soil conductivity between and across sites.

Longitudinal electric and magnetic 76 Hz fields were significantly different for test and controls (Tables 6-8), indicating that low amperage testing produced a "treatment" condition on test plots, compared to controls. For this reason, we must consider 1985 as our last pre-operation year.

The release sites for tree swallow homing studies compared to their respective study plots showed low ratios for control sites and higher ratios for test (Tables 6-8). Ratios generally increased from 1986 to 1990, although transverse fields showed a drop in 1988 and increased again in 1989 and 1990 (Tables 6-8).

### Comments on Ambient Monitoring

We have elected to use weather station data from several nearby sites to monitor the effects of climatic conditions impinging on the plots. The plots are relatively close to each other and therefore experience the same major weather patterns. Minor differences probably exist due to variations in storm tracks, local topography and vegetative features. These differences will produce some degree of variability in response in our study animals, but in most cases we expect this to be small and random in direction. It is therefore our judgment that the greatest value of station weather data will be for examination of year to year effects, rather than within a year among plots.

There is one instance where we have become aware of an effect that is probably based on micro-climatic differences among the plots. The abundance of aerial insects that are preyed upon by tree swallows is greater on control plots (data still in preparation). However, test plots may be less affected

## SMALL MAMMALS AND NESTING BIRDS 1990 ANNUAL REPORT

by cold weather due to the adjacent forest than control plots. We have instituted a program to sample aerial prey, in cooperation with Dr. D. Hussell in Ontario, Canada. The program is given in greater detail below in the sections dealing with population statistics and growth of tree swallows. This year we have the first results available, but they came too late to incorporate them into this draft report.

## SMALL MAMMALS AND NESTING BIRDS 1990 ANNUAL REPORT

### STUDY OF SMALL MAMMAL COMMUNITIES

#### I. Purpose

The small mammal community study was not conducted in 1989 or 1990. As we have stated in previous annual reports, differences between plots from year to year appear to be site specific and variable. Such variability does not allow us to examine ELF effects within the levels of our stated statistical goals. Therefore we felt the year to year variability, coupled with new budgetary constraints in 1989, would not allow us to adequately detect effects due to ELF. We therefore elected not to continue the small mammal community study.

## **SMALL MAMMALS AND NESTING BIRDS 1990 ANNUAL REPORT**

### **PARENTAL AND NESTLING BEHAVIOR, AND FECUNDITY, GROWTH AND MATURATION STUDIES - TREE SWALLOWS**

#### **I. Purpose**

The purpose of these studies is to characterize several aspects of the reproductive process in tree swallows at test and control sites and to test for possible effects of the ELF Communication System on these variables. Specifically, the following aspects of the reproductive process are compared between test and control sites and for each site from year to year: numbers of eggs per clutch, hatching success within clutches, rates of growth and development of hatchlings, and nestling mortality. All of these work elements are described together in this one section because they are all conducted on the same populations of birds.

#### **II. Methods**

These studies were conducted in natural or artificial clearings where we erected arrays of nest boxes. The boxes were made of cedar lumber and mounted on posts, 1.5 m above the ground. Tree swallows readily elected to nest in the boxes (Table 9) and tolerated considerable disturbance by investigators. The boxes could be opened to permit inspection and weighing of young. Sheets of high-density polyethylene wrapped around the posts prevented access by terrestrial predators. Tangle-foot insect repellent was used at the base of posts to prevent ants from getting into nestboxes.

When possible, adults were captured on the nest after incubation was completed and banded with U. S. Fish and Wildlife Service bands for identification. Since it has been shown that certain reproductive variables are affected by the age of the female (DeSteven 1978), most of our effort was

## SMALL MAMMALS AND NESTING BIRDS 1990 ANNUAL REPORT

placed on capturing females. In addition, as many young as possible were banded before fledging.

Active nests were checked daily or every other day on one test plot (Pirlot Road) and a control plot (Tachycineta Meadows) to determine the dates that eggs were laid, numbers laid, hatching dates of the young, and hatching success. These data were used to assess fecundity and mortality in detail. Other test plots, with the exception of Ford South and North test plots which are used for embryological studies (see Table 1), and one other control plot were checked less frequently following hatching. Data from these plots were used to examine overall mortality patterns on all plots, but in less detail than for the single test and control plots noted above. During hatching, nests were checked twice daily to determine with greater accuracy time of hatching as well as the spread of hatching over time. Monitoring of the nests for nestling growth and mortality then continued until all young reached 16 days of age. Young tend to fledge unusually early if disturbed beyond day 16. Therefore, after day 16, nest checks to estimate fledging success were done every other day to minimize disturbance.

For studies of growth and development, nestlings were weighed every other day with a Pesola spring scale accurate to 0.1 g. The lengths of the tarsus, ulna, and wing (all from the right side of the body) were measured with dial calipers accurate to 0.1 mm. Since it was impossible for one observer to measure all nestlings we had at least two observers collecting growth data. However, we have noticed that observers differ slightly in their techniques for measuring weights and body parts. Therefore we had all observers rotate among the plots so that every nestling was eventually measured by all observers. Regularly rotating the observers in this way has

## SMALL MAMMALS AND NESTING BIRDS 1990 ANNUAL REPORT

the effect of submerging the variance in measurement due to observers into the error in each nestling's growth curve. This measurement protocol unfortunately prevents us from being able to block observer effects in the statistical design. However, as we show below, when we use data from each individual bird's growth curve, even the significant effects of differences in observer technique do not prevent us from being able to detect small differences in patterns of growth.

For analysis of growth data, we used the procedure for fitting growth data to models of growth proposed by Ricklefs (1967, 1983) and used previously for tree swallows by Zach and Mayoh (1982). Briefly, the data for each nestling were subjected to curve fitting using an exponential model for wing growth and the logistic model for all other variables. The curve fitting was done using a nonlinear routine in SYSTAT (Wilkinson 1990). Data generated from the fitting routines were the growth constant (K) for the exponential model and the growth constant (K) and the inflection point for the logistic model. These variables were used in subsequent analyses to compare growth performance on test and control plots. In 1990, we also tested actual values for maximum size attained for weight, tarsus and ulna (wing is still growing at fledging) and the age these values were obtained. We also computed a linear growth rate for ages 3 to 11 days (the period of linear growth) for body weight and ulna length, and ages 3 to 8 days for tarsus length. We did this to supplement the curve-fitted data.

In past years we have detected a few significant differences in growth constants of young tree swallows between test and control plots. Recent evidence suggests that food availability on a plot can have a significant effect on both clutch sizes and growth rates of tree swallows (Hussell and



## SMALL MAMMALS AND NESTING BIRDS 1990 ANNUAL REPORT

Quinney 1987, Quinney et al. 1986). In order to determine what degree of variation between test and control plots in growth rates is the result of food resource availability, we have undertaken steps to quantify the flying insect abundance at each site. We have worked with Dr. Hussell of the Ontario Ministry of Natural Resources and have designed a sampling scheme based on his earlier work (see Hussell and Quinney 1987, for detailed methodology). At each tree swallow site we collected flying insects during the daylight hours in two suspended conical nets with alcohol traps. These nets were located among the nest boxes and were constructed to face passively in the wind so as to continually sample insects which either flew or were blown into the nets. Previous studies showed an excellent relationship between the insects collected in this type of system and the insects delivered to young swallows in the nest by their parents (Quinney and Ankney 1985). Sampling began before the initiation of any egg laying and ended when all young from the plot had fledged. After insects were sorted into size classes, we computed an index of the biomass of flying insects determined from daily catches on each plot. This allowed us to compare the prey abundances between test and control plots in order to look for explanations in differences in growth rates between plots not due to age of the adults or clutch sizes. These data will further refine our abilities to detect possible subtle differences in tree swallow reproductive measures due to electromagnetic fields associated with the Communication System. We now have the first completed data sets of insect biomass, but we received them too late to include in this report.

### III. Results - 1990

With increased return rates of nesting adults observed each year we have established plots which will provide adequate sample sizes for all of the

## SMALL MAMMALS AND NESTING BIRDS 1990 ANNUAL REPORT

tasks reported on below. Starting in 1986, we conducted all aspects of the research program on specific plots established for each individual task (see Table 1) and will continue with this protocol as originally proposed.

The age of adults breeding on the plots was quantified in earlier years by categorizing a bird as an adult if it had a high percentage of its dorsal plumage colored iridescent green. Younger birds have mostly a dark gray back plumage with little green (Hussell 1983a). In 1985, we found many more young birds nesting on control than test plots (Beaver et al 1986). In 1986, we were not able to make as complete a determination because many birds abandoned their nests due to inclement weather prior to the time we designated to assess age of adults. However, we did keep records of birds we saw on our daily visits to the plots. Less than 10% of nesting birds were young birds and there appeared to be equal numbers of them on test and control. In 1987, less than 20% of nesting birds were young birds, with greater numbers of young birds on the control plots. Of the nesting birds observed in 1989, 11% were known to be young females. In 1990, 14% of the nesting birds were young birds. The younger birds were observed exclusively on the control plots. This large number of young birds on the control plots may be reflective of an inherent difference in habitat quality between the two plots. Even if this is true, the collection of data from test and control both before and after antenna activation should enable us to sort out antenna effects and habitat effects, if we categorize effects on young versus older birds and their nests.

**Fecundity and Mortality.** First, we examine data obtained solely from the Pirlot Road test and the Tachycineta Meadows control plots. We will consider data from all plots below.

## SMALL MAMMALS AND NESTING BIRDS 1990 ANNUAL REPORT

Summarized fecundity data for tree swallows in 1990 and comparisons to years 1985-1989 (Table 10) indicate a slightly higher clutch size but lower hatch and fledge rates exists for control plots. These data exclude any renesting attempts. Mean clutch size in 1990 at Pirlot Road (5.1 eggs/nest) was smaller than clutches at Tachycineta Meadows (5.5 eggs/nest), and very nearly significantly different ( $t=1.91$ ,  $P=0.06$ ). Both of these values are within the range of those reported elsewhere for tree swallows (Chapman 1955, DeSteven 1978, Zach and Mayoh 1982, Hussell 1983b). When data on clutch size from the last five years are considered together (Table 12), we observe no significant effect due to plot ( $F=0.26$ ,  $P=0.610$ ), or year ( $F=1.05$ ,  $P=0.39$ ). This ANOVA indicates a significant plot X year interaction effect ( $F=2.64$ ,  $P=0.02$ ). The interaction results from clutch sizes increasing on the control plot every year since 1985 while remaining stable or decreasing on the test plot.

We have suspected there are differences in available food at the test and the control plots and this could be influencing clutch size, a finding reported for tree swallows in Canada by Hussell and Quinney (1987). As reported in past years, we are cooperating with Hussell in determining prey biomass at our sites and we should be able to examine this using the data we have on insect biomass as soon as the analysis of our insect data by Hussell is complete.

There was no difference in the distribution of clutch sizes between test and control plots during 1990 or in prior years (Table 10, G-test of independence,  $G=2.6$ ,  $P>0.1$ ).

Hatching success (Table 11) was slightly greater at the Pirlot Road test plot (94.6%) than at Tachycineta Meadows control plot (90.2%) during 1990

## SMALL MAMMALS AND NESTING BIRDS 1990 ANNUAL REPORT

but this difference in likelihood to hatch was not significant (G-test of independence, Sokal and Rohlf 1981,  $G=2.146$ ,  $df=1$ ,  $P>0.10$ ). When 1985-1990 data on likelihood to hatch are examined together, results show that rate of hatching is dependent upon plot and year combination (Table 11,  $G=27.70$ ,  $df=11$ ,  $P<0.005$ ). To determine if this lack of independence is influenced more greatly by plot or year, this contingency table was broken down by years (with data pooled over test and control plots) and treatment (test vs. control plot data pooled over years). The results show that likelihood to hatch is dependent upon year ( $G=19.00$ ,  $df=5$ ,  $P=0.005$ ), but not treatment ( $G=2.71$ ,  $df=1$ ,  $P>0.1$ ). The actual number of young that hatched per nest (Table 10) was slightly greater on the test (5.1 young/nest) than on the control (5.0 young/nest) in 1990. These values are not significantly different ( $t=-0.44$ ,  $P=0.66$ ) and fall within the range reported elsewhere (Low 1933, Paynter 1954). When hatch rate data from the last five years are considered together in an analysis of variance (Table 13), we find no significant effects due to plot or plot/year interaction (both  $P>0.30$ ). A significant difference was noted between years ( $P=0.0005$ ), due to higher numbers hatched per nest in 1986, 1988, and 1990 when compared to other years (Table 10).

Fledging success (Table 11) was greater at Pirlot Road (76.7%) than at Tachycineta Meadows (59.7%), and these differences in likelihood to fledge are significantly different ( $G=6.42$ ,  $df=1$ ,  $P>0.025$ ). This observed difference in likelihood to fledge between test and control was due primarily to predation by a bear at the control plot. Bear-caused mortality accounted for 31.8% of all mortality on the control plot. Without this mortality, fledging rates would have been virtually the same between test and control.

## SMALL MAMMALS AND NESTING BIRDS 1990 ANNUAL REPORT

When 1985-1990 fledging data from Pirlot Road and Tachycineta Meadows are analyzed together (Table 11), likelihood to fledge was found to be highly dependent upon year and plot combination ( $G=315.14$ ,  $df=11$ ,  $P<0.0001$ ). To determine if this lack of independence was influenced more greatly by plot or year, the contingency table was broken down by years (with data pooled over test and control plots) and treatment (test vs. control plot data pooled over years). The results show that likelihood to fledge was highly dependent upon year ( $G=305.32$ ,  $df=5$ ,  $P<0.0001$ ) as well as treatment ( $G=5.055$ ,  $df=1$ ,  $P<0.025$ ). The significant effect of year is due primarily to the greatly decreased likelihood to fledge associated with adverse weather following hatching during 1986 and 1989. The significant effect due to treatment is greatly influenced by the bear predation in 1990 on the control plots. With bear predation taken into account, this effect disappears ( $G=1.32$ ,  $df=1$ ,  $P>0.1$ ).

The actual number of young fledging per nest during 1990 (Table 10) was greater at the Pirlot Road test plot (3.7 young/nest) than at Tachycineta Meadows control (3.0 young/nest), but these values are not significantly different ( $t= -1.16$ ,  $P=0.253$ ). When data on actual numbers of young fledged per nest from the last six years are considered together in an analysis of variance (Table 14), we detect no significant effects due to plot (although a trend is apparent) or plot/year interaction. There was a highly significant effect of year ( $F=19.41$ ,  $P<0.0001$ ). This effect is primarily due to the episodes of inclement weather in 1986 and 1989 which severely limited the numbers of young fledged from most nests.

**Mortality at all Plots.** In addition the intensive study of fecundity on the Pirlot Road test and the Tachycineta Meadows control plots, we also monitored all active nests on all plots, except for Ford South and North test

## SMALL MAMMALS AND NESTING BIRDS 1990 ANNUAL REPORT

plots, which are used for embryology studies. Thus, three test plots pooled, two control plots pooled are the basis for an analysis of overall nesting success. The data obtained are not as complete as those just presented with regard to the frequency of observation. To analyze these data we used the Mayfield method (Mayfield 1961, 1975). The basis of the method is the analysis of the exposure of each egg and nestling to mortality factors over the number of days they are in the nest. The nest as a whole can also be examined this way, and we present data grouped by nest. We compared test and control plots for the frequencies of exposure days with mortality to those without mortality. For example, one nest with five eggs observed for four days would represent 20 egg days of exposure, or for the nest as a whole, four nest days of exposure. Data presented here include information from all years of study (Tables 15-19).

The number of exposure days with egg mortality in 1990 was higher on the test plots than on the control plots (Table 15,  $G=11.646$ ,  $P<0.001$ ). Exposure days with nestling mortality in 1990 was also higher on the test plots than on the controls (Table 16,  $G=15.581$ ,  $P<0.001$ ). During 1989 there was equal nestling mortality between test and control plots, but mortality was very high both places due to inclement weather (Beaver et. al. 1990).

The frequency of nest failure taken as a whole was significantly higher on the test plots in 1990 (Table 17,  $G=5.375$ ,  $P<0.025$ ) when compared to the controls. The same result was obtained in 1988. During 1989 there were no differences between test and control plots, possibly because of substantial weather-caused nest failure. When nest failure as a whole was examined by separating the incubation phase and the nestling phase, there were no differences detected between test and control plots (incubation phase,

## SMALL MAMMALS AND NESTING BIRDS 1990 ANNUAL REPORT

Table 18,  $G=2.508$ ,  $P>0.1$ ; nestling phase Table 19,  $G=2.361$ ,  $P>0.1$ ). Thus, it is the combined effects of the phases that is producing the significance for the whole nest rather than one particular phase of the nesting cycle.

Summarizing, the frequency of mortality of eggs, nestlings, and failures of entire nests was higher on the three test plots in 1990 compared to the two control plots. This is in contrast to 1989 when no differences were detected, probably due to high mortality of eggs, nestlings, and entire nests on all plots caused by inclement weather. However, the results in 1990 are consistent with those reported in 1988 (Beaver et. al. 1989).

Even though these differences are significant, we cannot at this time be certain that an effect of the antenna has been demonstrated. We strongly suspect the configuration of nest box placement in relation to the forest edge on the test plots is contributing to the higher mortality rates observed. The main factor is likely predation and interference by House Wrens (Troglodytes aedon). The physical sizes of the test plots are smaller than the controls. This size relationship effectively results in a greater relative proportion of edge on the test plots. House Wrens interfere with Tree Swallow nesting by destroying eggs and young in attempts to take over nest boxes for their own use. This degree of interference declines as this distance from the edge increases (our own data, Rendell and Robertson 1990). The edge effect is most pronounced at Cleveland Homestead and North Turner test plots where nest abandonment, egg mortality, predation of young, and total nest failure was highest. Pirlot Road test plot has less edge due to its shape. Increased edge may account for the significant differences observed (Tables 20-24) when the data are pooled for all test plots.

## SMALL MAMMALS AND NESTING BIRDS 1990 ANNUAL REPORT

Since these findings are inconsistent with the fecundity and mortality analysis we reported for Pirlot Road and Tachycineta Meadows above, we compared exposure data from these two plots by themselves. With data from just these two plots we were unable to detect differences in egg mortality ( $G=0.216$ ,  $P>0.5$ ), nestling mortality ( $G=0.388$ ,  $P>0.5$ ), and overall nest failure ( $G=0.292$ ,  $P>0.5$ ). This is in contrast to our overall exposure analysis (Tables 20-24), yet confirms our earlier results of no overall differences among these plots in our detailed analysis of fecundity and mortality presented in Tables 13 and 14, discounting predation by bears. Thus, we suspect that the differences we are detecting among pooled test and control plots are due to the greater degree of edge effect and the associated impact of House Wren interference on the test plots compared to controls, and not due to an effect of the antenna on survival.

We plan to more closely assess the effects of interference by House Wrens on our test plots in order to confirm this relationship of higher mortality rates and habitat edge effect.

In 1990, 327 adults were captured; 192 (58.7%) were new individuals and 135 (41.3%) were returns which were banded by us during previous seasons. The number of returning adults in 1990 was similar to 1989 (43.5%) and greater than previous years; 33.8% in 1988, 12.3% in 1987, 29.7% in 1986 and 16.6% in 1985. As many young as possible are banded before fledging; in 1990, 808 young were banded in the nest, 46% more than in 1989. In 1989, as in 1986, nest abandonment by the adults and the high mortality of young, caused by inclement weather, reduced the number of birds available for banding. The low number of returning birds in 1987 during nesting may be a reflection of the



## SMALL MAMMALS AND NESTING BIRDS 1990 ANNUAL REPORT

1986 cold weather, but it is puzzling that a similar effect was not detected in 1990 after severe mortality in 1989.

**Landmark growth events.** The mean number of days to eye opening in 1990 (Table 20) was longer at the Pirlot Road test plot (6.4 days) than at Tachycineta Meadows control (6.0 days), however these differences were not significant in analysis of variance (Table 21,  $P=0.253$ ). Eyes have opened later in other years, except 1986 (Table 20). In all years, there is a significant effect of nest on the age at eye opening (Table 21,  $P<.001$ ). The scoring of eyes closed or open in the field is somewhat subjective and may be biased depending upon observer, lighting conditions and other factors. In addition, we only observe the young on an every-other-day basis. The resulting increase in the variance further reduces our ability to detect subtle differences in age of eye opening. We will continue to score the age of eye opening, but with increased attention to problems in assessing the status of the eye.

Mean number of days to feather eruption in 1990 (Table 20) was the shortest in any year and very similar among plots (not significantly different, Table 22,  $P>0.63$ ). We have no indications as to why this was the case. No significant effects of plot were noted for any other years as well (Table 22). Like age at eye opening, in all years there is a significant effect of nest on the age at feather eruption (Table 22,  $P=.0001$ ). Contrasting feather eruption with eye opening, the eruption of primary feathers is generally a less variable measure than eye opening and is much less subjective in the field when the actual scoring takes place. We therefore have more confidence in using this variable as an assessment of ELF effects on developmental landmarks.

## SMALL MAMMALS AND NESTING BIRDS 1990 ANNUAL REPORT

**Statistical sufficiency of fecundity and maturation measures.** We have examined the statistical power of test and minimum detectable difference for the measures of fecundity discussed above (Table 23). We are currently able to detect changes of less than 10% of the mean for clutch size and hatch success, but 22% for fledge success. The power of these tests is very low. If we set the power of the test at 70% certainty, we are still able to detect differences of less than 10% for clutch size but only about 18% and 42% for hatch success and fledging success, respectively (Table 23).

Minimum detectable differences are larger for eye opening and feather eruption, but still all are below about 16%, with power again less than 30% (Table 24). With the power set to 70%, minimum detectable differences increase to greater than 25 and than 45%, depending on the year (Table 24). We will therefore be less confident of rejecting the hypothesis of no difference in plots for these variables given the current small differences in means.

**Growth.** Curve fitting to growth data for individual birds during 1990 for body mass, tarsus and ulna growth was accomplished using the logistic model while wing growth was fit by the exponential model. These models produce the highest  $R^2$  values, on average, compared to other growth models (see Ricklefs 1983, and Zach and Mayoh 1982, for discussion of various models). In addition, linear regression of growth data for weight, tarsus and ulna between the ages of 3 and 11 days were used to estimate growth rate. These days of growth are essentially linear. The maximum values attained in growth for these variables were also used to assess growth of nestlings on control and test plots.

## SMALL MAMMALS AND NESTING BIRDS 1990 ANNUAL REPORT

The logistic model was fitted to the data using a NONLIN procedure (Ricklefs 1983, Wilkinson 1988). The procedure estimated values for the growth rate constant and the inflection point for body mass, tarsus and ulna growth. The NONLIN procedure was also used to fit wing growth data to an exponential model of growth. A growth constant was estimated, but no inflection point occurred since the wing was still growing at the time of fledging. The growth and inflection point variables for each nestling were included in the data set if a significant correlation between the variable and age existed. The data were then analyzed using nested analysis of variance (NANOVA) with the effect of nests included within plots. Thus, the model may be written as:

$$Y_{ijk} = \mu + \alpha_i + B_{ij} + e_{ijk}$$

where  $Y_{ijk}$  is the  $k$ th observation in the  $j$ th subgroup of the  $i$ th group,  $\mu$  is the parametric mean of the population,  $\alpha_i$  is the fixed effect of the  $i$ th group (plots),  $B_{ij}$  is the random contribution of the  $j$ th subgroup (nests) and  $e_{ijk}$  is the error term. A nested model was used to account for the known effect of parents on the growth of their nestlings. Ricklefs and Peters (1981) studying the European starling (Sturnus vulgaris) in Pennsylvania found the most significant contribution of variance to total variance in growth was due to the parents rather than variation in individual nestling growth or inherited growth traits. Our data on tree swallows shows similar partitioning of the variance in growth. The appropriate ratio for testing for a treatment (plot) effect is the mean square due to plot with the mean square due to nests within plots rather than the error mean square. This reduces the effective sample  $N$  to the number of nests, rather than the number of nestlings, and has

## SMALL MAMMALS AND NESTING BIRDS 1990 ANNUAL REPORT

some important impacts on the power of the test. This will be discussed in detail below after summarizing the findings for 1990.

In general, growth constants and inflection points from the curve fitted data and linear growth rates, maximum values and ages at the maximum values were most strongly affected by nests within plots and least by plot (Tables 25 - 40). These results will be examined in turn below.

**Body mass** - Growth constants (Table 25), inflection points (Table 26), linear growth rate (Table 27), maximum weight attained (Table 28) and age at maximum weight (Table 29) showed no significant plot effects in 1990. Earlier years exhibited the same results with the exception of 1985 where significant or near significant plot effects were detected for inflection point, age of maximum weight and growth constant. The result appears to be due to slower growth of nestlings on the newly established control plot (see Tables 41-45 for means of growth measures). Younger adult birds nested on the control plot in 1985 compared to the test plot and it is known that they have poorer reproductive performance than second year and older adults (DeSteven 1978). A single other significant plot effect was found for inflection point in 1989 (Table 26). No corresponding effects were detected in other measures of body mass, so we tentatively conclude this is a random result.

**Tarsus growth** - The significant growth constant (Table 30) and inflection point (Table 31) for tarsus observed in 1989 did not recur in 1990 and must be considered as having been due to other, non-electromagnetic factors. Additionally, data on linear growth rate of the tarsus (Table 32), maximum size of tarsus (Table 33) and age at maximum tarsus size (Table 34) did not indicate an effect in 1989 or any other year except 1986 for maximum age (Table 34). In 1986, a cold spell occurred that affected growth, as also

## SMALL MAMMALS AND NESTING BIRDS 1990 ANNUAL REPORT

happened in 1989. Age at maximum tarsus length appears to have been accelerated on the test plot (Table 45) in both years, but not significantly so in 1989.

**Ulna growth** - An examination of ulna growth indicates that there were no plots effects for most years and measures (Tables 35-39). However, 1989 did produce a significant plot effect for inflection point (Table 36) and a nearly significant effect occurred for linear growth rate (Table 37). Maximum length of ulna showed a significant plot effect for 1986 and approached significance in 1987, 1988 and 1990 (Table 38). Examination of the mean values (Table 44) indicates ulna length was smaller on the control plot in three of the four years and larger in 1988. This suggests a trend for enhanced growth on the test plot but this is weakened by the lack of a difference in other years and the inconsistent result of 1988. A significant effect of plot was seen for maximum age at attaining ulna length in 1985 (Table 39). This effect can be attributed to the younger adults breeding on the control plot in that year, but the mean age (Table 46) was not much different in subsequent years. It seems more reasonable to attribute the effect to chance.

**Wing growth** - Growth of the wing was examined by fitting data to an exponential model to produce a growth constant. The wing does not have a linear phase during growth in the nest, and growth continues after nestlings fledge. Accordingly, we only have measures of the fitted growth constant to examine for possible ELF effects. No effects were detected in 1990 and none have occurred in any of the past research seasons (Table 40).

**Statistical sufficiency of growth measures** - We have examined the power of each performed test and the difference in means that can be detected with our current data (Zar, 1984, p 260). The results (Tables 46-50) indicate that

## SMALL MAMMALS AND NESTING BIRDS 1990 ANNUAL REPORT

we are able to detect differences in test versus control means of about 12% for curve fitted data, except for tarsus, where detectable differences were about 19 to 26% (Tables 46,47). These differences are detectable at very low power, generally less than 30%. When the certainty criterion is set to 70%, the corresponding minimum detectable difference increases to about 30% of the grand mean for all but the tarsus where it increases to about 42% for the growth constant and 62% for the inflection point. The corresponding values for linear growth rate are somewhat lower than fitted growth constants (Table 48), and much lower for maximum attained size and age at the maximum size (Tables 49-50) for the detectable difference and somewhat lower for the difference with a 70% certainty. The latter data provide greater confidence that impacts on growth would have been detected.

The analysis of power and detectable difference allows a more detailed examination of the method of analysis we are using for tree swallow growth. One striking feature of the growth data fitted to the logistic model (or any of the other growth models) is that the coefficient of variation is higher, by about 10%, for all variables compared to the raw data itself. Thus, the fitting procedure introduces additional, undesirable variation into the data, a finding reported by Zach (1988) as well. The least variable measure is maximum size for weight, tarsus length and ulna length (Table 44). Zach (1988) has suggested using this variable instead of fitted variables. While we will continue to report data fitted to the Logistic growth curve, it is clear that a better measure of the effects of ELF on growth is obtained by raw data or those obtained using the linear phase of growth.

## SMALL MAMMALS AND NESTING BIRDS 1990 ANNUAL REPORT

### PARENTAL AND NESTLING BEHAVIOR, AND FECUNDITY, GROWTH, AND MATURATION STUDIES - DEERMICE

#### I. Purpose

The purpose of these studies is to characterize several aspects of the reproductive process in deermice at test and control sites and to test for possible effects of the ELF Communication System on these variables. Specifically, the rates of growth and development of nestlings are compared between test and control sites and for each site from year to year. All of these work elements are described together in this one section because they are all performed on the same families of mice.

#### II. Methods

These studies were conducted within enclosures because free-ranging mice have been found not to remain resident in nest boxes for long enough periods for us to obtain the data desired. The enclosures are large: 6.1 by 5.8 m. Ten enclosures have been constructed within mixed deciduous forests at both the test and control plots. They are open at the top to allow free passage of atmospheric electromagnetic fields and free exposure to weather. Furthermore, they were constructed primarily of acrylic plastic sheeting, which is permeable to atmospheric electric fields according to IITRI engineers. Briefly, the walls of the enclosures consist of acrylic sheeting attached to cedar posts extending about 60 cm above ground and projecting about 15 cm below ground to prevent mice from digging out. A 51-cm-wide sheet of acrylic placed horizontally along the top of each wall prevented animals from climbing over the wall. Tree trunks were sheathed with sheets of high-density polyethylene to prevent mice from climbing in or out of the enclosures via the

## SMALL MAMMALS AND NESTING BIRDS 1990 ANNUAL REPORT

trees. Each enclosure was provided with a nest box and a feeding and watering station. The nest box can be opened to permit access to the mice.

Small enclosures (termed holding facilities or "hotels") built according to the same design, but measuring just 1.2 by 1.2 m, were also constructed at the same sites. These enclosures were used as holding facilities for mice awaiting study in the large enclosures. The mice to be studied were captured in mixed deciduous forest near the enclosure sites. They were set up as male-female pairs. Later the females were transferred into the large enclosures when visibly pregnant. They gave birth in the enclosures and reared their young to the age of weaning.

Newborn young were toe-clipped for identification when 4 days old. From then until they were 22 days old, their growth was followed by weighing every other day to an accuracy of 0.1 g using a Pesola scale. Initial litter size and subsequent deaths were recorded. The age of eye-opening and incisor eruption was recorded as an index of developmental rate.

### III. Results - 1990

The growth and development of 5 litters from 5 females at Pirlot test plot and 11 litters from 11 females at Michigamme control plot were monitored during 1990. Of the 16 females which dropped litters at Pirlot Road test plot 11 died or killed their litters. At the Michigamme control plot 16 females produced young, however, 5 abandoned or killed their litters. Adequate food and water were available at all times. Litters dropped later than the first week of June appear to be at high risk. Efforts to decrease mortality through partial burying of nestbox and keeping the area clean have met with minimal success. Cool weather appears to substantially increase our chances of obtaining complete datasets on litters dropped in enclosures.



## SMALL MAMMALS AND NESTING BIRDS 1990 ANNUAL REPORT

**Growth of Young.** A perusal of the growth in body mass of nestlings indicates that growth curves often appear non-linear. Although littermates consistently exhibit similarly shaped growth curves, there are apparent differences in curves among litters of different females as well as differences between litters of the same female (i.e., some are exponential, some sigmoidal, etc.). While this variability in the shape of growth curves among (but not within litters) is interesting, it precludes the use of any particular non-linear model (e.g., logistic growth model) to estimate and compare growth rates in these mice. Therefore, growth rates have been estimated using linear regression analyses for growth of each individual up to the time of weight recession which appears to be correlated with weaning (Table 51). Nested ANOVA of growth rate due to mothers nested with plot yielded a significant effect of mother but none due to plot for 1990, 1989 (although significance was approached), 1988, 1987 and 1986 (Table 52). At this writing, we do not have any hypotheses as to the nature of the mother effect, although we now suspect that the number of littermates may be of considerable importance, based on our preliminary analyses of the effects of number of young on growth rates in tree swallows.

The power of the test and the detectable differences were estimated for each year from 1986 to the present (Table 53). The minimum detectable difference ranged from about 11% in 1988 to a high of about 62% in 1989. Minimum detectable differences at 70% power are very large and variable from year to year, much more so than growth for tree swallows. Perhaps this reflects problems in field measurement, but we think it is more a function of the response of the deermice to captivity and handling. They are much more sensitive to handling than the birds.

## SMALL MAMMALS AND NESTING BIRDS 1990 ANNUAL REPORT

Age at eye opening was over two days earlier at the Pirlot Road test plot in 1990 (Table 54). Ages at incisor eruption were similar between plots in 1990 and other years (Table 54). Age at eye opening was significantly different among plots in 1990 and 1988 but not in other years (Table 55). A significant effect due to mother was observed every year (Table 55). Plot differences were not apparent for the age of incisor eruption (Table 56), however there was a significant effect attributable to mothers.

In general, power of the test for eye opening and incisor eruption were less than or equal to 30% and minimum detectable differences ranged from about 7% to 38% (Table 57). Actual power for the 1990 test for eye opening equalled 74%. At 70% power, minimum detectable differences vary from about 32% to over 167%. We therefore have relatively poor ability to see small changes in these variables that may result from ELF fields generated by the antenna.

Much of the variation in growth and maturation of young mice can be attributed to the frequency of visits we make to obtain the data (every other day) and also the apparently inherent response to disturbance caused while obtaining measurements. Thus an animal categorized as not having eyes open on a particular day will not be checked again for two days. This produces a built in error of two days. Thus, we do not feel we can obtain fine enough resolution for these variables to meet our statistical criteria without increasing the frequency of visits, yet it is also clear that handling is a major factor affecting growth of the nestlings. We are investigating the possibility of modifying our present work schedules to allow more frequent visits and also techniques that may minimize the effects of handling and disturbance.

## SMALL MAMMALS AND NESTING BIRDS 1990 ANNUAL REPORT

### HOMING STUDIES - TREE SWALLOWS

#### I. Purpose

The purpose of these studies is to measure the homing success of tree swallows at test and control sites and to test for possible effects of the ELF Communication System on such success. Variables measured are the proportions of swallows that successfully return home after displacement and the time required for each bird to return home. Birds returning to their nestbox within 300 minutes are considered successful.

#### II. Methods

Adult birds were captured at the nest box using a passive nest box trapping device (Magnusson 1984). Captures took place between 0800 and 1100 to allow adequate feeding of the young in the nest prior to capture. Following capture, each bird was sexed (using the presence of a cloacal protuberance for males and brood patch for females) and aged using plumage characteristics (Hussell 1983a). Birds were banded using a standard U.S. Fish and Wildlife band and were color marked on the breast using "magic markers" to provide rapid and positive identification while in flight. Birds were placed in wire cages which were covered with black cloths, and then driven to the release sites.

In our first studies of swallow homing in 1984 and 1985, we released birds at all four cardinal compass directions (east, west, north, south) at test and control sites. The results revealed no differences in homing success from one compass direction to another. Furthermore, because tree swallows probably home without regard to habitats they fly over and they are not likely to be exposed to any different hazards (predators, etc.) in homing from one direction as opposed to another, we feel justified in releasing birds at just

## SMALL MAMMALS AND NESTING BIRDS 1990 ANNUAL REPORT

one compass direction. Using just a single release point at test and control sites is more efficient in terms of personnel effort than use of four release points and thus permits adequate sample sizes to be obtained more easily.

The release points are located in open areas that are at a distance of 30 km from the nest sites and at a compass direction 20 degrees NE of the nest sites (Figure 1). This distance was chosen because it is greater than the distance corresponding to a drop of two orders of magnitude of potential electromagnetic fields given off by the Communications System. The direction of the release points in relation to the nest sites was chosen so that birds attempting to return to the test site in a straight line will cross both east-west legs of the antenna configuration, areas that would supposedly be maximally influenced by ELF electromagnetic fields. Upon release, the time, vanishing vector, and weather conditions were noted. Observers located near the nest boxes recorded the time at which the birds returned. Birds at each release site were released singly, with the subsequent bird released when the first had disappeared from sight (approximately 3 minutes).

### III. Results - 1990

Data were collected at Panola Plains control (PPC, 39 displacements), North Turner test (NTT, 24 displacements) and Cleveland Homestead test (CHT, 18 displacements).

Only one displaced bird failed to return to the two test plots, so their data were pooled to compare to the control plot. In past years we have compared likelihood to return before pooling, yet in 1990 there were too few numbers in the 'not return' category to allow testing. We assume there are no differences in likelihood to return at the two test plots in 1990.

## SMALL MAMMALS AND NESTING BIRDS 1990 ANNUAL REPORT

Results show a significant lack of independence between pooled test plots and the control (Table 44,  $G=8.527$ ,  $P<0.005$ ) with displaced birds more likely to return to the test plots. When return rates from 1986-1990 are assessed together, results show that overall likelihood to return is dependent upon treatment (test/control) and year combinations ( $G=27.74$ ,  $df=9$ ,  $P<0.005$ ). To determine if this lack of independence is influenced more greatly by treatment or years, this contingency table was broken down by treatments (test vs. control, pooled over years) and by years (pooled over test and control plots). Results show that likelihood to return is dependent upon treatment (Table 47,  $G=15.566$ ,  $df=1$ ,  $P<0.001$ ), but is independent of year ( $G=5.90$ ,  $df=4$ ,  $P>0.1$ ).

Mean time to return in 1990 was not different between the two test plots (NTT and CHT,  $t=0.49$ ,  $P=0.62$ ), so they were pooled for comparison to the control (PPC). Mean time to return was faster on the pooled test plots (148 minutes) than on the control (172 minutes), but this difference was not significant ( $t=1.84$ ,  $P=0.0699$ ). Although not statistically significant according to our stated criteria, the faster return times on the test plots represent a continuation of a trend which has persisted every year of the tree swallow homing study (1986-1990). When these data are assessed in an ANOVA (Table 46) significant effects of both plot ( $F=37.11$ ,  $P=0.0001$ ) and year ( $F=2.42$ ,  $P=0.0486$ ) are shown, with no plot by year interaction. The significant plot effect is a result of consistently faster return times on the test plots. The year effect shown is due to shorter overall return times in 1989 and the longer overall return times in 1987.

## SMALL MAMMALS AND NESTING BIRDS 1990 ANNUAL REPORT

Overall, analyses show that displaced birds from the test plots exhibit a higher likelihood to return as well as showing faster return times. The reason for the observed differences remains unexplained.

In 1990 we attempted to test the possibility that there are properties unique to our Panola Plains control site which could be contributing to the overall observed differences. We compared likelihood to return and return times for displaced birds from Panola Plains to birds displaced from Tachycineta Meadows, a plot not previously used for homing studies. Displaced birds from both plots were released from the normal Panola Plains release site which effectively controlled for any release site characteristics. Due to time constraints we were only able to displace 13 birds from TMC. Likelihood to return was shown to be independent of plot ( $G=2.276$ ,  $P>0.1$ ) even though 76.9% returned at PPC compared to 53.8% returning at TMC. The distances travelled by the returning birds was slightly shorter for TMC birds (26.7 km) compared to PPC (30 km), so rate of km/hr return speed was used for comparison rather than minutes to return. Return speeds were significantly faster for birds returning to PPC compared to return speeds at TMC (11.4 km/hr vs. 8.6 km/hr,  $t=2.037$ ,  $P=0.049$ ).

Even though sample sizes are small at TMC, these results suggest that the observed differences may be due to plot effects rather than a release point effect. Although these results suggest differences in plot characteristics between TMC and PPC rather than problems with the common release point, they do not help explain the observed differences over five years between normal test and control plots. Our efforts to determine the reasons for these continued observed differences will continue.

## SMALL MAMMALS AND NESTING BIRDS 1990 ANNUAL REPORT

Power of the test of return time yields a detectable difference of about 24% at a power of greater than 99% (Table 48). If we apply our relaxed standard of 70% power, then differences as small as 10% in returns should be detectable using our current sample sizes and research protocol.

### HOMING STUDIES - SMALL MAMMALS

#### I. Purpose

The purpose of these studies is to measure the homing success of small mammals at test and control sites and to test for possible effects of the ELF Communication System on such success. Variables measured are the proportions of individuals that successfully return home after displacement and the time required for each individual to return home. The principal species studied are deermice and chipmunks.

#### II. Methods

During our initial studies on mammal homing in 1985 (Beaver, et al. 1986), we displaced chipmunks and deermice in all four cardinal directions in order to investigate any directional biases in homing ability. No such biases were found even though animals displaced west and north on the control and test plots had to cross the sham corridor or actual antenna corridor, as well as somewhat different habitat types. However, our sample sizes were small for any particular displacement direction (maximum of 10 animals) and we therefore could not be certain of the robustness of our tests. Thus, in contrast to the work on swallow homing, we decided to reduce the number of displacement directions to two rather than one. Reducing the number of directions from four to two increased efficiency of sampling. By using two directions rather than one, however, we maintained the diversity of habitats and corridor crossings

## SMALL MAMMALS AND NESTING BIRDS 1990 ANNUAL REPORT

at each site, thus helping to insure that we are further able to examine the effects of habitat conditions as well as potential effects of ELF on homing behavior.

The small mammal homing study was conducted on two trapping grids, one at the Pirlot road test site and the other at the Michigamme control site. Due to the low chipmunk and deermouse populations noted in 1985 and 1986, the size of the trapping grid was increased in 1987. Each grid contained 100 stations spaced 15 meters apart rather than ten meters, therefore increasing the area covered to 1.8 ha versus 0.81 ha as before. One Leathers live-trap was placed at each station, baited with peanut butter and rolled oats. The grids were situated on the east side of both the ELF ROW and the sham ROW. A habitat buffer between each ROW and its respective trapping grid was increased in 1987 to 50 meters, rather than the 10 meters of 1985. This increase helped insure that both the grids and their displacement lines were located in more uniform habitat, a continuous mixed deciduous forest dominated by sugar maple (Acer saccharum).

Trapping began on 6 July and ended on 30 July, 1990. Traps were checked twice daily (ca. 0800 and 1700) and rebaited as necessary. Because of the small sample sizes obtained for other species in 1985, only eastern chipmunks and woodland deermice were displaced in the following years. Each animal was weighed, sexed, and toe-clipped or ear-tagged for individual identification. Reproductive condition, station number, and capture time were also recorded. Individuals were kept for displacement after their third capture; such animals were deemed to be residents of the area where the trapping grid was established which, hopefully, insured their detection by continued recapture on the trapping grid upon returning from displacement. Before being



## SMALL MAMMALS AND NESTING BIRDS 1990 ANNUAL REPORT

displaced, each animal was kept in a laboratory cage supplied with nesting material, lab chow, and water. Cages were placed in screened-in storage sheds located near each site. Displacements took place during, or just prior to, the next activity period following capture; deermice (nocturnal) were displaced at dusk (ca. 1900) and chipmunks (diurnal) were displaced in the morning (ca. 0800). Each animal was displaced 450 m from the trap it was captured at when kept for displacement. Displacements took place to the south and west of the home grids. The exact point of release was adjusted to reflect the point of capture on the home grid; this way all individuals were displaced exactly the same distance from their capture point. Trapping continued for five days after the last animal was displaced.

The displacements to the south were through continuous forest, whereas those to the west required returning animals to cross the antenna corridor at the test site and the sham corridor at the control site. Use of the two displacement directions thus specifically allowed us to test for directional differences in return rates which might occur due to the fact that animals returning from the west must pass beneath the antenna line, potentially the area of greatest electromagnetic disturbance.

### III. Results - 1990

The following analyses are based only on the antenna operational years of 1989 and 1990. Previous years of 1986, 1987, and 1988 represent times of pre-operational antenna testing as well as smaller sample sizes available for the homing studies due to low small mammal population numbers.

A total of 44 chipmunks (23 test, 21 control) and 78 deermice (43 test, 35 control) were displaced in 1990 (Table 49). No differences in likelihood

## SMALL MAMMALS AND NESTING BIRDS 1990 ANNUAL REPORT

to return were detected between the two displacement directions for either species, so the data were pooled.

For chipmunks, there were no differences in likelihood to return between test and control sites in 1990 ( $G=2.477$ ,  $P>0.1$ ) or in 1989 ( $G=0.306$ ,  $P>0.5$ ). When both years are examined together the same conclusion is reached (overall  $G=2.844$ ,  $df=3$ ,  $P>0.1$ ). For deer mice, there were significant differences in likelihood to return both in 1989 ( $G=4.83$ ,  $P<0.05$ ) and 1990 ( $G=11.234$ ,  $P<0.001$ ). Although a significant lack of independence is also shown when both years are examined together ( $G=18.401$ ,  $df=3$ ,  $P<0.001$ ), this is due to an interaction between treatment and year. In 1990 displaced deer mice were more likely to return to the control plot when compared to the test plot, and the opposite trend is true in 1989 (see percentage returned in Table 49).

How these observed differences are related to individual plot deer mouse populations or antenna operation is not clear. More information from antenna operational years will be required for a more solid assessment.

### DEVELOPMENTAL STUDIES

#### I. Purpose

The purpose of these studies is to characterize aspects of normal development in tree swallows and to investigate potential effects of ELF radiation on development. Specifically, early embryological development of tree swallows is being characterized, developmental abnormalities in field populations of tree swallows are being described and their incidence in test and control plots is being determined. The sizes of eggs collected from test and control plots is being compared.

## SMALL MAMMALS AND NESTING BIRDS 1990 ANNUAL REPORT

### II. Methods

Tree swallow eggs were collected from nests during late May and early June. Entire clutches were removed from 15 nests in control plots TMC and PPC and 16 nests in test plots FST and FNT exposed to ELF irradiation. Nests were inspected daily and eggs were numbered as they were laid. Eggs were collected 4 days after the appearance of the last egg. A total of 160 eggs were inspected.

Collection of eggs and subsequent analyses were carried out by different investigators to avoid bias. Each nest was coded in such a way that the investigator carrying out the analysis was unaware of the test or control status of eggs until analysis was completed.

Egg sizes were determined in three ways. Eggs were weighed to two decimal places on a Sybron Digimetric balance. Measurements of egg volumes were obtained by water displacement. Finally, length and breadth of eggs were measured using vernier calipers.

All embryos were dissected off the yolk into Howard Chick Ringers solution (Johnson and Volpe, 1973), analyzed briefly by microscopic observation and fixed in either Bouin's solution for further observation and histological study or 2.5% glutaraldehyde in Howard Ringers for scanning electron microscopy.

Embryos placed in Bouin's were fixed for 24 hours and dehydrated through a graded series of ethanols. Embryos were stained as whole mounts with either an alcoholic carmine solution or an alcoholic eosin solution (Watterson and Schoenwolf, 1984), dehydrated and cleared in methyl salicylate. All embryos were then carefully observed using an Olympus stereomicroscope using transmitted light and a photographic record of each was obtained. The use of

## SMALL MAMMALS AND NESTING BIRDS 1990 ANNUAL REPORT

methyl salicylate as clearing agent allows material to be observed as a whole mount and stored without undue tissue hardening. Subsequently, material can be embedded in paraffin and used for routine histology.

### III. Results - 1990

**Normal development.** The early embryology of tree swallows closely parallels that of the chick as described by Hamburger and Hamilton (1951). By 4 days incubation, many embryos had reached Stage 21, a few stage 23. Development was somewhat slower than in previous years, perhaps because of low climatic temperatures in 1990. As reported previously (Beaver, Hill and Asher 1986, Beaver, Hill and Hill 1990), an asynchrony of development is observed in this species. The last egg to be laid routinely lags several stages behind the others. This asynchrony seems to depend on the nesting behavior of females who are frequently observed to spend time on the nest before the clutch is complete. Such behavior is not restricted to tree swallows, but is common among small, altricial passerines (Clark and Wilson, 1985).

**Abnormal development.** Development of the following morphological structures was checked for each embryo - brain, eye, ear, heart, branchial arches, spinal cord and somites, limb buds, allantois, amnion and the flexion and rotation of the embryo. The types and frequencies of abnormalities are shown in Table 64.

Two eggs from the test plot showed no development. Eggs appeared to have been fertilized but development did not proceed beyond an abortive primitive streak. In addition, two entire nests containing 5 and 6 eggs from test plots showed only very slight development. Note is made of these nests; however, the 11 eggs involved are not included in the analysis of abnormalities at this time. Since no embryos were developing, it seems more

## SMALL MAMMALS AND NESTING BIRDS 1990 ANNUAL REPORT

likely that parents abandoned incubation than that specific developmental abnormalities occurred.

As reported last year, abnormalities involving the spinal cord were the most common. Ten embryos from test plots and 11 from control plots showed spinal abnormalities. Of these, 8 from test plots and 9 from control plots had spinal cords that appeared wavy, S-shaped or too short. Three of the 9 from control plots also had the allantois dorsally directed. In addition, 2 embryos from a test plot nest and 2 embryos from a control plot nest showed dented backs. This particular abnormality shows a strong "nest effect" and was reported in 1989, again equally divided between test and control sites.

A condition which may be similar has been reported by Wytttenbach and Hwang (1984) and Garrison and Wytttenbach (1985). These investigators found that chick embryos exposed to organophosphate insecticides develop wry neck, short neck and other cervical defects including vertebral fusion. They conclude that the primary effect of the insecticide is on the notochord which appears folded.

In a total of 8 embryos, the allantois is beginning to develop posteriorly instead of anteriorly. (Five of these are apparent in Table 64. The other 3 are included under "spinal abnormalities" because they show both defects.) The significance of the early direction of the allantois is not known. To date, dorsally-directed allantois have been observed only in stage 18 and 19 embryos, while the allantois is very small. It seems highly probable that as development proceeds, the allantois swings ventrally and normal development ensues. For this reason, the results have been analyzed both including and excluding allantois development.

## SMALL MAMMALS AND NESTING BIRDS 1990 ANNUAL REPORT

**Frequency of abnormalities.** To determine the significance of the frequency of abnormalities, Chi square analyses were carried out on normal and abnormal embryos from test versus control plots. Because the determination of "abnormal" is not always clear-cut, as described above, tests were carried out in two ways. Table 65, a contingency table, shows the analysis of embryos when the 5 with the posteriorly directed allantois are considered normal. Table 66 shows the analysis when these 5 are grouped with the abnormal animals. In both cases, very low values for  $X^2$  (0.02 and 0.17) were obtained, indicating that there is no difference in the frequency of abnormalities detected in test and control plots.

As in previous years, the overall incidence of abnormalities is quite high (Beaver, Hill and Asher 1989, Beaver, Hill and Hill 1990). In 1990, approximately 19% of the embryos inspected were abnormal; this figure rises to 23% if embryos with dorsally directed allantois are included.

A significant increase in abnormalities has been reported in chick embryos exposed to magnetic fields over 16.7 Hz (Juutilainen and Saali 1986, Juutilainen et al. 1986). These investigators exposed chick embryos to magnetic fields ranging from 1 Hz to 100 kHz using various wave forms. They found a 13% abnormality rate in control embryos which rose from 16% to as high as 56% in test groups exposed to 16.7 Hz, 30 Hz, 50 Hz, 1 kHz, 10 kHz and 100 kHz. Under test conditions, the most frequently encountered abnormality was disruption of the nervous system. While the curved and dented backs we report could result from disruption of the nervous system, the extent of abnormality they show is much greater than observed in our test sample. Clearly further study is warranted.

## SMALL MAMMALS AND NESTING BIRDS 1990 ANNUAL REPORT

**Dented eggs.** Each year a few eggs (5 in 1990) are dented before they are opened, either by the birds during normal nesting procedures or by humans during handling and numbering. In most cases the embryos inside damaged eggs are abnormal. The abnormalities in dented eggs generally fall into 2 categories. Either there is very little development or the embryos form tissues appropriately but appear too thick, too short and have abnormally curled spines. The most conservative interpretation is that abnormal development results from shell damage, perhaps from evaporative water loss and drying out of tissues. On the other hand, it is possible that abnormal development precedes denting and that shells of embryos that are not developing or are doing so abnormally are more fragile than those of normal eggs.

In support of this latter interpretation is the finding that dented eggs sometimes appear in nests where other embryos are also abnormal. For example, in nest 16, eggs #1, 2 and 3 all contained abnormal embryos. Egg #3 was dented and was the most abnormal, but eggs #1 and 2 also contained embryos that were too curled, too short and too thick surrounded by membranes that were also too thick. Similarly, nest #17 contained a total of 6 eggs, 3 of which, #2, 3, and 4 were abnormal. Numbers 2 and 4 both showed virtually no development, although they appeared to have been fertilized. Egg #4 was dented in the nest. (Egg #3 contained a microcephalic embryo and #1, 5 and 6 were normal).

To try to determine cause and effect, 12 eggs were dented by investigators in 2 nests and left for further incubation. Three eggs in the 2 nests were eliminated by the parent birds. Of the remaining 9 eggs, 5 showed an abnormal development and one, a failure to develop. Of the 5, 3 had the

## SMALL MAMMALS AND NESTING BIRDS 1990 ANNUAL REPORT

appearance described previously in naturally dented eggs. It seems probable, then that the embryological abnormalities seen in dented eggs result from shell damage. Consequently, we will continue to follow the procedure used previously and eliminate dented eggs from the data pool.

**Size of eggs.** Since avian embryos must develop in a closed system, the resources allocated to each offspring during oogenesis could have a marked influence in determining chick survival. If females forage less effectively in some situations than in others, eggs may be of lower nutrient value and chick survival compromised. To determine whether ELF radiation affects the amount of nutrient deposited in eggs, each egg, at the time of collection, was measured in three ways. First, each was weighed. Second, volume measurements were obtained using a water displacement method. Means of egg volumes for each nest from test and control plots are given in Table 67. Third, length (L) and breadth (B) of each egg was measured using vernier calipers. Basic statistics are shown in Table 68.

Weights of eggs from test and control plots were compared using a nested ANOVA (Table 69). Weights differed significantly among nests but no plot effect was found.

Similarly, volumes of eggs from test and control plots were compared using a nested ANOVA (Table 70). Again, a significant nest effect was found but no significant difference was detected between test and control plots.

This year (1990) was the first year that volume measurements were obtained for the entire sample. Last year, eggs from three nest were measured and their volumes used to calculate a constant, K, based on the formula  $V_{egg} = K_v B^2 L$ . In 1989, a value for K = 0.499 or 0.50 was determined. In 1990,



## SMALL MAMMALS AND NESTING BIRDS 1990 ANNUAL REPORT

using a much larger sample size and a more accurate volume measurement, a value of  $K = 0.49$  was calculated.

**Comparisons with other species.** The development of the domestic chick is the standard against which most other species are measured. Early tree swallow development closely parallels chick development, although some differences such as the amount of constriction of the eye stalk and the relative size of wing buds compared to leg buds are apparent. These differences are being analyzed. This year a sample of older embryos was collected from an area near the study site so that the comparison with chick embryos can be extended to hatching. These studies are currently underway.

### STUDIES OF MAXIMUM AEROBIC METABOLISM

#### I. Purpose

The purpose of these studies is to measure the peak aerobic metabolism of animals during winter at test and control sites and to test for possible effects of the ELF Communication System on peak metabolism. The principal species studied are chickadees and deermice.

#### II. Methods

**Collection and care of birds.** To attract chickadees for study, feeding stations were established in December and kept stocked throughout the winter with sunflower seeds. Chickadees were mist netted as needed from these stations. Upon capture, birds were weighed to the nearest 0.1 g using a Pesola spring scale and marked with a colored plastic leg band for individual identification. When released from captivity, they were banded using a standard U.S. Fish and Wildlife Service band for permanent marking. Birds were housed singly in wire mesh cages (28 x 18 x 31 cm). Shelled sunflower seeds and snow or water were available ad libitum. In addition, each morning

## SMALL MAMMALS AND NESTING BIRDS 1990 ANNUAL REPORT

and late afternoon, meal worms were provided in excess. The cages were kept in a screened outdoor holding facility, which provided natural lighting and temperature conditions.

**Collection and care of mammals.** Trap shelters were established in late November, prior to any substantial snowfall. The shelters were located along wandering lines situated approximately 75-250 m from the antenna or sham corridor. The habitat was northern hardwoods dominated by maple, basswood, and elm, typical of the area. Each shelter was a plastic waste container placed upside-down on top of the ground layer, with a covered top opening which provided the researcher access to the ground layer once snow was present. Mice entered the shelters through the interface between the ground layer and the wall of the shelter. One Leathers live trap was placed in the bottom of the shelter and baited with rolled oats, peanut butter, and sunflower seeds. Polyester batting was provided in the trap for nesting material. Traps were prebaited and left open one month prior to actual trapping to insure that small mammals would include the stations in their subnivean runways. Researcher travel on the sites was by snowshoe along a single trail to minimize disturbance of the subnivean air spaces which are critical to small mammal movements.

Trapping was begun at the start of January and continued intermittently, according to need for animals, through March. Work was focused primarily on the deer mouse. Upon capture, individuals were toe-clipped for identification, sexed and weighed to the nearest 0.1 g with a Pesola spring scale. Once at the lab, animals were transferred to standard plastic lab cages (29 x 18 x 13 cm) with wire lids and provided with wood shavings, polyester batting, and a diet of sunflower seeds, lab chow, and apple and snow for moisture. Cages were

## SMALL MAMMALS AND NESTING BIRDS 1990 ANNUAL REPORT

housed in an open outdoor facility which provided natural lighting and temperature conditions.

**Laboratory methods.** To elicit a peak rate of oxygen consumption, we used a refined version of the helium-oxygen (helox) method first introduced to the study of small-animal physiology by Rosenmann and Morrison (1974). Placing an animal in a helium-oxygen atmosphere at a given ambient temperature greatly increases the individual's rate of heat loss by comparison to the rate in air (mostly nitrogen-oxygen), due to the relatively much higher thermal conductivity of helox. Thus, the animal must produce heat more rapidly in helox than air if it is to maintain a stable body temperature.

Whether the rate of oxygen consumption measured in helox is in fact a true peak metabolic rate depends partly upon the ambient temperature. Identifying the true peak for an individual therefore entails studying the animal at a series of ambient temperatures. Specifically, study at a minimum of three ambient temperatures is required for a definitive determination: there should be a measurement at the temperature that elicits the peak, and also there should be measurements at temperatures higher and lower, demonstrating that the rate of oxygen consumption in helox falls off if the temperature is either raised or lowered from that eliciting the peak. Of course, the temperatures of interest are unknown at the onset of work on an individual. Thus, in principle, many measurements would have to be made on an individual before its peak would be definitively identified. In practice, experience often permits us to know in advance the temperature at which the peak will occur. Therefore, we often need to test an animal at just three temperatures to establish its peak definitively. The spacing we have used between temperatures is 5°C. Thus, if we test an animal in helox at three

## SMALL MAMMALS AND NESTING BIRDS 1990 ANNUAL REPORT

ambient temperatures that are 5°C apart (e.g. -10, -5, 0°C) and if the highest measured rate of oxygen consumption occurs at the middle temperature, we conclude that we have identified the animal's peak rate definitively.

Tests were not carried out on the day of capture to reduce any effect of capture stress. To further avoid adverse effects of stress, animals were tested only once on any given day.

Prior to a test animals were weighed to the nearest 0.1 g on an Ohaus triple-beam balance, and their body temperature ( $T_b$ ) was measured by inserting a copper-constantan thermocouple probe 2-3 cm colonically. Then each animal was placed into a metabolic chamber. Chambers were constructed from new one-half gallon paint cans, with inflow and outflow ports in the lid. The inside surfaces were painted with 3M ECP-2200, for an emissivity of nearly 1.0. A 0.5-inch-mesh hardware cloth floor covered with Dip-It plastic coating was used to elevate the animal above the bottom of the can, thus helping to insure proper airflow around the animal and permitting urine and feces to drop away so as not to wet the animal. The outflow port of each chamber houses a 36-gauge copper-constantan thermocouple to monitor chamber temperature, which is maintained by immersion of the can in a Forma Scientific 2325 water bath using ethanol as antifreeze. All temperature probes are connected to a Leeds and Northrup 250 Series Multipoint recorder which can be read to the nearest 0.1°C.

Measurements were carried out during daylight hours. Food was provided during measurements. Specifically, apple was provided for the mammals, and shelled sunflower seeds and a mealworm were provided for the chickadees. The metabolism chambers for the birds were equipped with a small light that provided dim illumination; without this light, the chickadees (which are

## SMALL MAMMALS AND NESTING BIRDS 1990 ANNUAL REPORT

diurnal feeders) would not eat. Our decision to provide food during tests is based on extensive preliminary experimentation and is predicated on the following considerations: (1) Animals in nature are able to feed during the day; the birds are diurnal foragers, and the mammals can feed from caches. (2) In the mice, the variance in results is lower when food is provided than when it is denied. (3) In the birds, there is evidence that fasting during these types of experiments increases the probability of death.

Oxygen consumption was measured using an open-flow system. Briefly, gas (air or helox) was pumped through the metabolic chamber at a measured flow rate, and the reduction in its oxygen content was measured. From these data, the rate of oxygen use of the animal could be calculated. The oxygen content of gases was measured with an Applied Electrochemistry S3A oxygen analyzer and recorded on a Houston Superscribe potentiometric recorder. Gas flow rates were measured with Brooks 1110 rotameters. The rate of oxygen consumption was calculated according to the formulas in Hill (1972a, method B), taking cognizance of the mathematical relationship between gas composition and the output of the S3A analyzer. We have empirically verified that the S3A analyzer reads oxygen levels in helox with the same accuracy as in air.

Animals were provided with air during an initial adjustment period (0.7-1.5 hr) and then switched to helox. Flow rates were 600 ml/min in air and 900 ml/min in helox. The adjustment period in air was terminated once the metabolic rate remained approximately stable for 15 to 20 minutes. Upon switching to helox, a rapid transition to the new gas was made by purging the metabolic chamber at a rate of 5 liters/min for two minutes. Then the rate of flow was reduced to the 900 ml/min already mentioned. The maximal rate of oxygen consumption under the test conditions was generally achieved within 15-

## SMALL MAMMALS AND NESTING BIRDS 1990 ANNUAL REPORT

20 minutes after the switch to helox, and animals were rarely exposed to helox for more than 25 minutes. Following the measurement in helox, animals were quickly removed from the metabolic chamber, and a final  $T_b$  and weight were recorded. All thermocouples have been calibrated against thermometers whose calibration is traceable to the National Bureau of Standards. Flowmeters have been calibrated against a Brooks Volumeter also having a NBS-traceable calibration.

The one aspect of the measurement procedure that is open to significant subjective judgment is the determination of the particular time interval over which the maximum oxygen consumption occurred in each experiment. Because of the subjectivity involved in this determination, a "blind" procedure will be used once the Communication System antenna has been turned on and high-resolution comparisons of test and control sites are being carried out. The relevant raw data, as earlier noted, are recorded using a potentiometric recorder. These records are not marked as to the origin of the animals (test or control site) but instead are identified simply by arbitrary, randomly assigned numbers. The final and definitive reading of the records will be carried out by a person who knows only these arbitrary numbers.

### III. Results - 1990

Measures of peak metabolic rate were obtained on 22 deermice and 24 chickadees in the winter of 1990. All these measures were obtained within the first week after capture.

The data were analyzed as specified in the 1988 annual report. It will be recalled that measures of peak metabolic rate are assigned to 10 quality rating classes. Classes 1, 2, 3, and 4 represent peak determinations of highest quality. Classes 0 and 5-9 represent peak determinations rated as

## SMALL MAMMALS AND NESTING BIRDS 1990 ANNUAL REPORT

acceptable but nonideal. Statistical comparisons of sets of peak metabolic rates have been carried out using an analysis of covariance design unless otherwise specified. The logarithm of whole-body peak metabolic rate has been used as the dependent variable, and the logarithm of body weight has been used as the covariate. The reasons for the use of analysis of covariance and those for performing the analysis in the logarithmic domain are detailed in the 1988 annual report. Normality of the logarithmically transformed data for peak metabolic rates and body weights was assessed using probit plots, and homogeneity of variances was evaluated with Bartlett's test. Both normality and homogeneity of variances were found to be acceptable in all analyses.

**Analysis of peak metabolic rates of deermice.** The first step in this analysis was to determine if a difference existed between measures of peak metabolic rate that were rated in quality classes 1-4 (primary quality) and measures that were rated in the other quality classes (secondary quality). This was done by pooling all data from both test and control plots into an analysis of covariance with a single factor: primary versus secondary quality rating. As in the past (see 1989 annual report), the difference between the quality rating categories for deermice proved nonsignificant ( $P = 0.07$ ). Thus, for analysis of plot effects, all peaks were pooled regardless of their quality rating. A single-factor analysis of covariance was performed on these pooled peaks, the factor being plot (test versus control). The effect of the covariate (body weight) was highly significant ( $P < 0.001$ ). However, there was no significant difference between test and control plots ( $P = 0.83$ ). Summary statistics are given in Table 71. We conclude that, for the deermice, peak metabolic rates measured in the first week after capture did not differ between test and control plots in 1990.

## SMALL MAMMALS AND NESTING BIRDS 1990 ANNUAL REPORT

**Analysis of peak metabolic rates of chickadees.** The first step in the analysis was again to determine if a difference existed between measures of peak metabolic rate that were rated in quality classes 1-4 (primary quality) and measures that were rated in the other quality classes (secondary quality). This was done, as for deermice, by pooling all data from both plots into an analysis of covariance with a single factor: primary versus secondary quality rating. Unlike the case in past years (see 1989 annual report), the difference between the quality rating categories for chickadees proved to be nonsignificant ( $P = 0.41$ ), and thus, all peaks were pooled regardless of their quality rating for analysis of plot effects. In that analysis, the effect of the covariate (body weight) was marginally nonsignificant ( $P = 0.06$ ). Robustly, there was no significant difference between plots ( $P = 0.88$ ). Summary statistics are given in Table 71. We conclude that, for the chickadees, peak metabolic rates measured in the first week after capture did not differ between test and control plots in 1990.

**Antenna operating parameters and the significance of the 1990 data.** The winter of 1990 was the first winter in the course of the Michigan Ecological Monitoring Program during which the ELF Communications System was operating at full power and for most hours of the day. It was also the first winter during which a substantial fraction of the operation of the antenna was in the frequency-modulated mode. The winter of 1990 thus provided our first opportunity to assess the effects of the Communications System on peak metabolic rates with the System operating approximately in its fully operational configuration.

Specifically, in January-March of 1990, according to records provided to us through IITRI, the mean operating current of the Communications System was



## SMALL MAMMALS AND NESTING BIRDS 1990 ANNUAL REPORT

150 amp, the NS arm was operational 91% of the time, and operation was principally or entirely modulated (72-80 Hz). By contrast, during January-March of 1989 (the winter when the System was heretofore at its highest operational level), the mean operating current was 75 amp, the NS arm was operational for only 6% of the time, and operation was principally unmodulated (at 76 Hz).

The data for the first winter in the near-full operating mode indicate that the electric and magnetic fields generated by the fully operational ELF Communications System will be unlikely to affect the peak abilities of nearby, resident deermice or chickadees to take up or use oxygen. This conclusion needs to be further assessed by increasing the sample sizes for both species through the addition of data from future winters.

**Sample sizes.** The means and standard deviations of the weight-specific peak metabolic rates measured in both species in 1990 were similar to those obtained in earlier years. Thus, minimal sample sizes required to meet our stated minimal standards of statistical sufficiency (detection of a 20% difference between test and control plots at the 5% level of significance with 90% certainty) remain unchanged from those earlier computed (see 1989 annual report). Provided the Communications System remains in a near-full operational mode in future winters so that data from the winter of 1990 and future winters can meaningfully be pooled, sample sizes will ultimately exceed the computed minimums by a good margin, and we will be in a position to detect smaller differences between test and control plots with greater certainty. We believe that sample sizes should be expanded as fully as possible within contractual time and budget constraints. This is a well-constrained data set (coefficients of variation are low relative to other measures that are or

## SMALL MAMMALS AND NESTING BIRDS 1990 ANNUAL REPORT

could be obtained on free-living populations). Thus, the data set provides a particularly promising opportunity to detect small effects if they are present, and we believe that opportunity should be exploited.

### CONCLUSIONS

In conclusion, our findings to date show, for the most part, that our plots do not differ in the many variables we are measuring (Table 72). In a few cases, we have found differences that could be due to the antenna system. These variables are: homing frequency and return times in tree swallows, homing frequency in deermice, age of eye-opening in deermice and growth of tarsus in tree swallow nestlings. We are now in a good position to compare data from pre-antenna years, years of antenna testing at greatly reduced output and the final years of full strength antenna operation.

SMALL MAMMALS AND NESTING BIRDS 1990 ANNUAL REPORT

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**SMALL MAMMALS AND NESTING BIRDS 1990 ANNUAL REPORT**

**APPENDIX A - TABLES AND FIGURES**



SMALL MAMMALS AND NESTING BIRDS 1990 ANNUAL REPORT

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# **SMALL MAMMALS AND NESTING BIRDS 1990 ANNUAL REPORT**

Table 1. Test-control plot pairings for the various work elements for small mammals and nesting birds. Plot code designations are those used by IITRI.

| STUDY ELEMENT                               | TEST PLOT                                    | CONTROL PLOT                                       |
|---|--|--|
| Deermouse Growth & Maturation               | PIRLOT ROAD<br>(1T1)                         | MICHIGAMME NORTH<br>(1C1)                          |
| Small Mammal Homing                         | PIRLOT ROAD<br>(1T1)                         | MICHIGAMME SOUTH<br>MICHIGAMME NORTH<br>(1C3, 1C1) |
| Deermouse Winter Physiology                 | PIRLOT ROAD<br>(1T1)                         | MICHIGAMME SOUTH<br>(1C1)                          |
| Tree Swallow Growth & Maturation            | PIRLOT ROAD<br>(1T1)                         | TACHYGINETA MEADOW<br>(1C6)                        |
| Tree Swallow Homing<br>(Home Plots)         | CLEVELAND<br>HOMESTEAD<br>(1T2)              | PANOLA PLAINS<br>(1C4)                             |
|   | NORTH TURNER<br>ROAD (1T4)                   | PANOLA PLAINS<br>(1C4)                             |
| (Displacement Plots)                        | CLEVELAND<br>HOMESTEAD<br>DISPLACEMENT (1D1) | -  |
|   | NORTH TURNER<br>DISPLACEMENT (1D2)           | -  |
|   | -  | PANOLA PLAINS<br>DISPLACEMENT (1D3)                |
| Tree Swallow Embryology                     | CLEVELAND<br>HOMESTEAD<br>(1T2)              | TACHYGINETA MEADOW<br>(1C6)                        |
|   | FORD RIVER<br>NORTH (1T5)                    | PANOLA PLAINS<br>(1C4)                             |
|   | FORD RIVER<br>SOUTH (1T6)                    |  |
| Black-capped Chickadee<br>Winter Physiology | PIRLOT ROAD<br>(1T1)                         | MICHIGAMME NORTH<br>(1C1)                          |

# SMALL MAMMALS AND NESTING BIRDS 1990 ANNUAL REPORT

Note: Cleveland Homestead, Ford River North and Ford River South plots are small. Therefore they have been designated solely as tree swallow embryology study sites.

Table 2. Mean values for 60 Hz transverse electric fields (V/m) on control and test plots paired by research activity. The values in parentheses are the sample n. Values listed by IITRI as <0.001 are treated as equal to 0.001.

| PLOT                                  | 1983-1985        | 1986             | 1987             | 1988             | 1989             | 1990             |
|---------------------------------------|------------------|------------------|------------------|------------------|------------------|------------------|
| Control                               |                  |                  |                  |                  |                  |                  |
| 1C1                                   | 0.001 (4)        | 0.001 (2)        | 0.001 (2)        | 0.001 (2)        | 0.001 (2)        | 0.001 (2)        |
| 1C3                                   | 0.001 (5)        | 0.001 (2)        | 0.001 (2)        | 0.001 (2)        | 0.001 (2)        | 0.001 (2)        |
| 1C4                                   | 0.001 (7)        | 0.001 (3)        | 0.001 (3)        | 0.001 (3)        | 0.001 (3)        | 0.001 (3)        |
| 1C6                                   | <u>0.001 (4)</u> | <u>0.001 (3)</u> | <u>0.001 (3)</u> | <u>0.001 (3)</u> | <u>0.001 (3)</u> | <u>0.001 (3)</u> |
| Average                               | 0.001 (20)       | 0.001 (10)       | 0.001 (10)       | 0.001 (10)       | 0.001 (10)       | 0.001 (10)       |
| Tree Swallow release site             |                  |                  |                  |                  |                  |                  |
| 1D3                                   | -                | 0.001 (1)        | 0.001 (1)        | 0.001 (1)        | 0.001 (1)        | 0.001 (1)        |
| Test                                  |                  |                  |                  |                  |                  |                  |
| 1T1                                   | 0.001 (11)       | 0.001 (14)       | 0.001 (14)       | 0.028 (18)       | 0.015 (8)        | 0.005 (18)       |
| 1T2                                   | 0.001 (3)        | 0.001 (4)        | 0.046 (5)        | 0.013 (5)        | 0.004 (5)        | 0.017 (5)        |
| 1T4                                   | 0.001 (4)        | 0.001 (5)        | 0.001 (10)       | 0.014 (10)       | 0.002 (10)       | 0.031 (10)       |
| 1T5                                   | 0.001 (5)        | 0.001 (6)        | 0.001 (9)        | 0.037 (9)        | *                | 0.046 (9)        |
| 1T6                                   | <u>0.001 (4)</u> | <u>0.001 (1)</u> | <u>0.001 (7)</u> | <u>0.078 (7)</u> | *                | <u>0.037 (7)</u> |
| Average                               | 0.001 (27)       | 0.001 (30)       | 0.025 (45)       | 0.034 (49)       | 0.007 (23)       | 0.027 (49)       |
| Tree Swallow release sites (Averaged) |                  |                  |                  |                  |                  |                  |
| 1D1 & 1D2                             | -                | 1.251 (2)        | 0.001 (2)        | 4.601 (2)        | 0.372 (2)        | 0.678 (2)        |

\* measurement precluded by antenna operation.

## KEY TO RESEARCH ACTIVITIES AND PLOT PAIRS:

|  |                   |
|--|-------------------|
| Growth and Maturation - Tree swallows  | 1C6 and 1T1       |
| Deermice                               | 1C1 and 1T1       |
| Embryology of Tree Swallows            | 1C4 and 1T2       |
|  | 1C6 and 1T5 + 1T6 |
| Homing - Tree Swallows                 | 1C4 and 1T2 + 1T4 |
| Deermice + Chipmunks                   | 1C1 + 1C3 and 1T1 |
| Winter Maximal Metabolism - Chickadees | 1C1 and 1T1       |
| Deermice                               | 1C1 + 1C3 and 1T1 |

# SMALL MAMMALS AND NESTING BIRDS 1990 ANNUAL REPORT

Table 3. Mean values for 60 Hz longitudinal electric fields (mV/m) on test and control plots for years 1983 to 1990. The values in parentheses are the sample n. Plot 1D3 is the release site for tree swallows used in homing studies on control plots, and plots 1D1 and 1D2 are release sites used for test plots.

| PLOT                              | 1983-1985        | 1986             | 1987             | 1988             | 1989             | 1990             |
|-----------------------------------|------------------|------------------|------------------|------------------|------------------|------------------|
| CONTROL                           |                  |                  |                  |                  |                  |                  |
| 1C1                               | 0.093 (5)        | 0.100 (2)        | 0.114 (2)        | 0.338 (2)        | 0.137 (2)        | 0.056 (2)        |
| 1C3                               | 0.158 (5)        | 0.080 (2)        | 0.148 (2)        | 0.117 (2)        | 0.178 (2)        | 0.110 (2)        |
| 1C4                               | 0.039 (7)        | 0.065 (3)        | 0.047 (3)        | 0.048 (3)        | 0.024 (3)        | 0.022 (3)        |
| 1C6                               | <u>0.079 (4)</u> | <u>0.068 (3)</u> | <u>0.089 (3)</u> | <u>0.041 (3)</u> | <u>0.079 (3)</u> | <u>0.066 (3)</u> |
| Average                           | 0.092 (20)       | 0.076 (10)       | 0.100 (10)       | 0.136 (10)       | 0.105 (10)       | 0.064 (10)       |
| Tree Swallow homing release site  |                  |                  |                  |                  |                  |                  |
| 1D3                               | -                | 0.052 (1)        | 0.156 (1)        | 0.053 (1)        | 0.290 (1)        | 0.260 (1)        |
| TEST                              |                  |                  |                  |                  |                  |                  |
| 1T1                               | 0.116 (11)       | 0.070 (14)       | 0.070 (14)       | 0.252 (18)       | 0.080 (8)        | 0.068 (18)       |
| 1T2                               | 0.196 (3)        | 0.074 (4)        | 0.059 (5)        | 0.075 (5)        | 0.047 (5)        | 0.051 (5)        |
| 1T4                               | 0.174 (4)        | 0.086 (5)        | 0.076 (10)       | 0.110 (10)       | 0.046 (10)       | 0.167 (10)       |
| 1T5                               | 0.253 (5)        | 0.079 (6)        | 0.078 (9)        | 0.159 (9)        | *                | 0.181 (9)        |
| 1T6                               | <u>0.569 (3)</u> | <u>0.230 (1)</u> | <u>0.297 (7)</u> | <u>1.324 (7)</u> | *                | <u>0.406 (7)</u> |
| Average                           | 0.262 (26)       | 0.080 (30)       | 0.108 (45)       | 0.384 (49)       | 0.058 (23)       | 0.175 (49)       |
| Tree Swallow homing release sites |                  |                  |                  |                  |                  |                  |
| 1D1 & 1D2                         | -                | 5.035 (2)        | 1.280 (2)        | 0.715 (2)        | 1.695 (2)        | 1.275 (2)        |
| (Averaged)                        |                  |                  |                  |                  |                  |                  |

\* measurement precluded by antenna operation.

# SMALL MAMMALS AND NESTING BIRDS 1990 ANNUAL REPORT

Table 4. Mean values for 60 Hz magnetic fields (Mg) on test and control plots for years 1983 to 1990. The values in parentheses are the sample n. Values listed by IITRI as <0.001 are treated as equal to 0.001. Plot 1D3 is the release site for tree swallows used in homing studies on control plots, and plots 1D1 and 1D2 are release sites used for test plots.

| PLOT                             | 1983-1985        | 1986             | 1987             | 1988             | 1989             | 1990             |
|----------------------------------|------------------|------------------|------------------|------------------|------------------|------------------|
| CONTROL                          |                  |                  |                  |                  |                  |                  |
| 1C1                              | 0.001 (4)        | 0.001 (2)        | 0.001 (2)        | 0.001 (2)        | 0.001 (2)        | 0.001 (2)        |
| 1C3                              | 0.002 (5)        | 0.001 (2)        | 0.001 (2)        | 0.001 (2)        | 0.001 (2)        | 0.001 (2)        |
| 1C4                              | 0.002 (7)        | 0.001 (3)        | 0.002 (2)        | 0.001 (3)        | 0.001 (3)        | 0.002 (3)        |
| 1C6                              | <u>0.003 (4)</u> | <u>0.003 (3)</u> | <u>0.003 (3)</u> | <u>0.002 (3)</u> | <u>0.003 (3)</u> | <u>0.003 (3)</u> |
| Average                          | 0.002 (20)       | 0.002 (10)       | 0.002 (9)        | 0.001 (10)       | 0.002 (10)       | 0.002 (10)       |
| Tree Swallow homing release site |                  |                  |                  |                  |                  |                  |
| 1D3                              | -                | 0.003 (1)        | 0.002 (1)        | 0.002 (1)        | 0.013 (1)        | 0.009 (1)        |
| TEST                             |                  |                  |                  |                  |                  |                  |
| 1T1                              | 0.003 (11)       | 0.009 (14)       | 0.010 (14)       | 0.052 (18)       | 0.018 (8)        | 0.008 (18)       |
| 1T2                              | 0.001 (3)        | 0.025 (4)        | 0.018 (5)        | 0.010 (5)        | 0.006 (5)        | 0.018 (5)        |
| 1T4                              | 0.001 (4)        | 0.012 (5)        | 0.021 (10)       | 0.018 (10)       | 0.007 (10)       | 0.033 (10)       |
| 1T5                              | 0.001 (5)        | 0.018 (6)        | 0.026 (9)        | 0.047 (9)        | *                | 0.038 (9)        |
| 1T6                              | <u>0.001 (3)</u> | <u>0.020 (1)</u> | <u>0.033 (7)</u> | <u>0.094 (7)</u> | *                | <u>0.035 (7)</u> |
| Average                          | 0.001 (26)       | 0.014 (30)       | 0.020 (45)       | 0.044 (49)       | 0.010 (23)       | 0.026 (49)       |
| Tree Swallow release sites       |                  |                  |                  |                  |                  |                  |
| 1D1 & 1D2                        | -                | 0.057 (2)        | 0.080 (20)       | 0.023 (2)        | 0.078 (2)        | 0.073 (2)        |
| (Averaged)                       |                  |                  |                  |                  |                  |                  |

\* measurement precluded by antenna operation.

# SMALL MAMMALS AND NESTING BIRDS 1990 ANNUAL REPORT

Table 5a. 60 Hz Transverse electric field intensities (V/m) at the laboratory site where maximal metabolic measures were being taken.

| Site No.,<br>Meas. Pt. | 1986  | 1987  | 1988  | 1989 | 1990                |       |
|------------------------|-------|-------|-------|------|---------------------|-------|
|                        |       |       |       |      | Before<br>Shielding | After |
| 1L1-1                  | /     | --    | --    | --   | --                  | --    |
| 1L1-2                  | 0.94  | 0.96  | --    | --   | --                  | --    |
| 1L1-3                  | 0.79  | 0.034 | /     | /    | /                   | 0.58  |
| 1L1-4                  | 0.042 | 0.047 | 0.062 | /    | /                   | /     |
| 1L1-5                  | -     | -     | -     | /    | /                   | /     |
| 1L1-6                  | -     | -     | -     | /    | /                   | /     |
| 1L1-7                  | -     | -     | -     | 8.1  | 8.5                 | 1.34  |
| 1L1-8                  | -     | -     | -     | 0.88 | 0.76                | 0.037 |
| 1L1-9                  | -     | -     | -     | 60.0 | 18.1                | 3.90* |
| 1L1-10                 | -     | -     | -     | -    | /                   | 0.010 |

- measurement point not established.

-- measurement point dropped.

/ data not taken.

\* 4.0 V/m with humidifier on.

# SMALL MAMMALS AND NESTING BIRDS 1990 ANNUAL REPORT

Table 5b. 60 Hz magnetic flux densities (Mg) made at the laboratory where maximal metabolic measures were being made.

| Site No.,<br>Meas. Pt. | 1986  | 1987  | 1988  | 1989              | 1990               |
|------------------------|-------|-------|-------|-------------------|--------------------|
| 1L1-1                  | 9.13  | --    | --    | --                | --                 |
| 1L1-2                  | 0.179 | 0.156 | --    | --                | --                 |
| 1L1-3                  | 0.080 | 0.143 | /     | /                 | 0.071              |
| 1L1-4                  | 0.114 | 0.118 | 0.080 | 0.075             | /                  |
| 1L1-5                  | -     | -     | -     | 14.1 <sup>a</sup> | 5.2 <sup>c</sup>   |
|                        |       |       |       | 21.0 <sup>b</sup> | 0.62 <sup>d</sup>  |
| 1L1-6                  | -     | -     | -     | 3.2 <sup>a</sup>  | 2.4 <sup>c</sup>   |
|                        |       |       |       | 44.0 <sup>b</sup> | 0.195 <sup>d</sup> |
|                        |       |       |       |                   | 0.081 <sup>e</sup> |
| 1L1-7                  | -     | -     | -     | 0.65              | 1.69               |
| 1L1-8                  | -     | -     | -     | 1.46              | 0.88               |
| 1L1-9                  | -     | -     | -     | 48.0              | 0.86               |
| 1L1-10                 | -     | -     | -     | -                 | 0.75               |

<sup>a</sup> measurement made in vertical orientation only in an open, unshielded can, submerged to its rim.

<sup>b</sup> measurement made above the bath surface.

<sup>c</sup> measurement made in closed, unshielded, fully submerged can.

<sup>d</sup> measurement made in closed, shielded, fully submerged can.

<sup>e</sup> measurement made in closed, shielded, fully submerged can with motor and pump shielding.

- measurement point not established.

-- measurement point dropped.

/ data not taken.

# SMALL MAMMALS AND NESTING BIRDS 1990 ANNUAL REPORT

Table 6. Mean values for 76 Hz transverse electric fields (V/m) on test and control plots for years 1986 (4 amperes), 1987 (15 amperes), 1988 (75 amperes), 1989 and 1990 (150 amperes). The value in parentheses is the sample N. NS refers to the north-south antenna segment. Standard phasing occurs in 1989 and 1990. All measures on test plots were made on the NS segment, except for displacement plots 1D1 and 1D2, which are located north of the northernmost EW segment. All values reported by IITRI as <0.001 were set to 0.001.

| PLOT                             | TRANSVERSE FIELDS (V/m) |                   |                   |                    |                    |
|----------------------------------|-------------------------|-------------------|-------------------|--------------------|--------------------|
|                                  | 1986<br>(4 amps)        | 1987<br>(15 amps) | 1988<br>(75 amps) | 1989<br>(150 amps) | 1990<br>(150 amps) |
| CONTROL                          |                         |                   |                   |                    |                    |
| 1C1                              | 0.001 (2)               | 0.001 (2)         | 0.001 (2)         | 0.001 (2)          | 0.001 (2)          |
| 1C3                              | 0.001 (2)               | 0.001 (2)         | 0.001 (2)         | 0.001 (2)          | 0.001 (2)          |
| 1C4                              | 0.001 (2)               | 0.001 (3)         | 0.001 (3)         | 0.001 (3)          | 0.001 (3)          |
| 1C6                              | <u>0.001 (3)</u>        | <u>0.001 (3)</u>  | <u>0.001 (3)</u>  | <u>0.001 (3)</u>   | <u>0.001 (3)</u>   |
| Average                          | 0.001 (9)               | 0.001 (10)        | 0.001 (10)        | 0.001 (10)         | 0.001 (10)         |
| Tree Swallow homing release site |                         |                   |                   |                    |                    |
| 1D3                              | 0.001 (1)               | 0.001 (1)         | 0.001 (1)         | 0.001 (1)          | 0.001 (1)          |
| TEST                             |                         |                   |                   |                    |                    |
| 1T1                              | 0.078 (14)              | 0.264 (14)        | 0.897 (18)        | 1.834 (18)         | 2.000 (18)         |
| 1T2                              | --                      | 0.301 (5)         | 1.710 (5)         | 2.540 (5)          | 2.819 (5)          |
| 1T4                              | 0.140 (5)               | 0.424 (10)        | 1.936 (10)        | 3.851 (10)         | 4.373 (10)         |
| 1T5                              | 0.283 (5)               | 0.790 (9)         | 3.614 (9)         | 6.531 (9)          | 11.002 (9)         |
| 1T6                              | <u>0.182 (1)</u>        | <u>0.544 (7)</u>  | <u>2.458 (7)</u>  | <u>5.275 (7)</u>   | <u>7.070 (7)</u>   |
| Average                          | 0.171 (25)              | 0.465 (45)        | 2.123 (49)        | 4.006 (49)         | 5.453 (49)         |
| Tree Swallow release sites       |                         |                   |                   |                    |                    |
| 1D1 & 1D2<br>(Averaged)          | 0.001 (2)               | 0.001 (2)         | 0.001 (2)         | 0.009 (2)          | 0.012 (2)          |

-- measurement point not established.



# SMALL MAMMALS AND NESTING BIRDS 1990 ANNUAL REPORT

Table 7. Mean values for 76 Hz longitudinal electric fields on test and control plots for years 1986 (4 amperes), 1987 (15 amperes), 1988 (75 amperes), 1989 and 1990 (150 amperes). The value in parentheses is the sample N. NS refers to the north-south antenna segment. Standard phasing occurred in 1989 and 1990. All measures on test plots were made on the NS segment, except for displacement plots 1D1 and 1D2, which are located north of the northernmost EW segment. All values reported by IITRI as <0.001 were set to 0.001.

| PLOT                              | LONGITUDINAL FIELDS (Mv/m) |                   |                   |                    |                    |
|-----------------------------------|----------------------------|-------------------|-------------------|--------------------|--------------------|
|                                   | 1986<br>(4 amps)           | 1987<br>(15 amps) | 1988<br>(75 amps) | 1989<br>(150 amps) | 1990<br>(150 amps) |
| CONTROL                           |                            |                   |                   |                    |                    |
| 1C1                               | 0.021 (1)                  | 0.085 (2)         | 0.430 (2)         | 1.505 (2)          | 1.185 (2)          |
| 1C3                               | 0.022 (1)                  | 0.068 (2)         | 0.335 (2)         | 0.960 (2)          | 0.895 (2)          |
| 1C4                               | 0.001 (1)                  | 0.003 (3)         | 0.013 (3)         | 0.046 (3)          | 0.044 (3)          |
| 1C6                               | <u>0.001 (1)</u>           | <u>0.005 (3)</u>  | <u>0.020 (3)</u>  | <u>0.079 (3)</u>   | <u>0.074 (3)</u>   |
| Average                           | 0.011 (4)                  | 0.040 (10)        | 0.200 (10)        | 0.648 (10)         | 0.550 (10)         |
| Tree Swallow homing release site  |                            |                   |                   |                    |                    |
| 1D3                               | 0.008 (1)                  | 0.053 (1)         | 0.210 (1)         | 0.850 (1)          | 0.890 (1)          |
| TEST                              |                            |                   |                   |                    |                    |
| 1T1                               | 1.089 (14)                 | 4.244 (14)        | 19.900 (18)       | 40.606 (18)        | 39.433 (18)        |
| 1T2                               | --                         | 7.500 (5)         | 34.600 (5)        | 76.200 (5)         | 73.600 (5)         |
| 1T4                               | 2.162 (5)                  | 7.390 (10)        | 36.300 (10)       | 74.400 (10)        | 72.300 (10)        |
| 1T5                               | 1.670 (5)                  | 6.600 (9)         | 28.444 (9)        | 63.222 (9)         | 62.333 (9)         |
| 1T6                               | <u>5.400 (1)</u>           | <u>18.457 (7)</u> | <u>83.857 (7)</u> | <u>162.286 (7)</u> | <u>181.714 (7)</u> |
| Average                           | 2.580 (25)                 | 8.838 (45)        | 40.620 (49)       | 83.343 (49)        | 85.876 (49)        |
| Tree Swallow homing release sites |                            |                   |                   |                    |                    |
| 1D1 & 1D2<br>(Averaged)           | 0.068 (2)                  | 0.320 (2)         | 1.365 (2)         | 8.650 (2)          | 8.150 (2)          |

-- measurement point not established.

# SMALL MAMMALS AND NESTING BIRDS 1990 ANNUAL REPORT

Table 8. Mean values for 76 Hz magnetic fields (Mg) on test and control plots for years 1986 (4 amperes), 1987 (15 amperes), 1988 (75 amperes), 1989 and 1990 (150 amperes). The value in parentheses is the sample N. NS refers to the north-south antenna segment. Standard phasing occurs in 1989 and 1990. All measures on test plots were made on the NS segment, except for displacement plots 1D1 and 1D2, which are located north of the northernmost EW segment. All values reported by IITRI as <0.001 were set to 0.001.

| PLOT                              | MAGNETIC FIELDS (mG) |                   |                   |                    |                    |
|-----------------------------------|----------------------|-------------------|-------------------|--------------------|--------------------|
|                                   | 1986<br>(4 amps)     | 1987<br>(15 amps) | 1988<br>(75 amps) | 1989<br>(150 amps) | 1990<br>(150 amps) |
| CONTROL                           |                      |                   |                   |                    |                    |
| 1C1                               | 0.001 (1)            | 0.001 (2)         | 0.003 (2)         | 0.007 (2)          | 0.007 (2)          |
| 1C3                               | 0.001 (1)            | 0.001 (2)         | 0.003 (2)         | 0.008 (2)          | 0.008 (2)          |
| 1C4                               | 0.001 (1)            | 0.001 (3)         | 0.001 (3)         | 0.002 (3)          | 0.002 (3)          |
| 1C6                               | <u>0.001 (1)</u>     | <u>0.001 (3)</u>  | <u>0.001 (3)</u>  | <u>0.004 (3)</u>   | <u>0.004 (3)</u>   |
| Average                           | 0.001 (4)            | 0.001 (10)        | 0.002 (10)        | 0.005 (10)         | 0.005 (10)         |
| Tree Swallow homing release site  |                      |                   |                   |                    |                    |
| 1D3                               | 0.001 (1)            | 0.001 (1)         | 0.002 (1)         | 0.008 (1)          | 0.008 (1)          |
| TEST                              |                      |                   |                   |                    |                    |
| 1T1                               | 0.143 (14)           | 0.530 (14)        | 2.251 (18)        | 4.921 (18)         | 4.593 (18)         |
| 1T2                               | --                   | 1.164 (5)         | 5.538 (5)         | 11.800 (5)         | 10.860 (5)         |
| 1T4                               | 0.278 (5)            | 1.050 (10)        | 5.410 (10)        | 10.700 (10)        | 10.160 (10)        |
| 1T5                               | 0.408 (5)            | 1.409 (9)         | 6.600 (9)         | 13.678 (9)         | 13.256 (9)         |
| 1T6                               | <u>0.400 (1)</u>     | <u>1.043 (7)</u>  | <u>4.889 (7)</u>  | <u>9.843 (7)</u>   | <u>10.114 (7)</u>  |
| Average                           | 0.307 (25)           | 1.039 (45)        | 4.938 (49)        | 10.188 (49)        | 9.797 (49)         |
| Tree Swallow homing release sites |                      |                   |                   |                    |                    |
| 1D1 & 1D2<br>(Averaged)           | 0.001 (2)            | 0.002 (2)         | 0.007 (2)         | 0.090 (2)          | 0.105 (2)          |

-- measurement point not established.

# SMALL MAMMALS AND NESTING BIRDS 1990 ANNUAL REPORT

Table 9. Tree swallow plots, number of boxes, and percent with egg laying activity on test and control sites for 1985 through 1990. Egg laying activity is defined as at least two eggs laid before abandonment or continuation of nesting.

| PLOT NAME                   | NUMBER OF<br>BOXES | % ACTIVITY |      |      |      |      |      |
|-----------------------------|--------------------|------------|------|------|------|------|------|
|                             |                    | 1985       | 1986 | 1987 | 1988 | 1989 | 1990 |
| CLEVELAND HOMESTEAD TEST    | 39                 | 58         | 62   | 66   | 74   | 68   | 51   |
| FORD NORTH TEST             | 16                 | 30         | 47   | 41   | 47   | 41   | 50   |
| FORD SOUTH TEST             | 21                 | 25         | 55   | 70   | 55   | 70   | 67   |
| NORTH TURNER TEST           | 53                 | 23         | 60   | 70   | 68   | 60   | 62   |
| PIRLOT ROAD TEST            | 36                 | 75         | 72   | 78   | 75   | 83   | 86   |
| PANOLA PLAINS CONTROL       | 164                | 43         | 77   | 87   | 85   | 90   | 84   |
| TACHYCINETA MEADOWS CONTROL | 75                 | 43         | 69   | 79   | 85   | 92   | 81   |
| TOTALS                      |                    |            |      |      |      |      |      |
| TEST                        | 165                | 44         | 61   | 68   | 68   | 66   | 64   |
| CONTROL                     | 239                | 43         | 73   | 83   | 85   | 90   | 83   |
| OVERALL                     | 404                | 44         | 67   | 76   | 77   | 80   | 75   |

# **SMALL MAMMALS AND NESTING BIRDS 1990 ANNUAL REPORT**

Table 10. Tree swallow fecundity data for years 1985-1990. Data are from the Pirlot Road test plot and Tachycineta Meadows control plot and excludes any renests which may have occurred.

| Variable                                      | Year | TEST |           |      | CONTROL |           |      |
|---|------|------|-----------|------|---------|-----------|------|
|   |      | n    | $\bar{X}$ | SD   | n       | $\bar{X}$ | SD   |
| Clutch Size <sup>a</sup>                      | 1990 | 31   | 5.1       | 0.98 | 61      | 5.5       | 0.72 |
|   | 1989 | 27   | 5.1       | 0.91 | 69      | 5.4       | 0.84 |
|   | 1988 | 26   | 5.4       | 0.81 | 61      | 5.3       | 0.85 |
|   | 1987 | 24   | 5.0       | 0.75 | 55      | 5.2       | 0.81 |
|   | 1986 | 23   | 5.3       | 0.88 | 48      | 4.9       | 1.01 |
|   | 1985 | 21   | 5.4       | 0.87 | 19      | 4.8       | 0.86 |
| Hatch Rate <sup>b</sup>                       | 1990 | 24   | 5.1       | 0.97 | 41      | 5.0       | 1.24 |
|   | 1989 | 20   | 4.3       | 1.29 | 51      | 4.2       | 1.37 |
|   | 1988 | 18   | 5.0       | 0.84 | 43      | 4.8       | 1.23 |
|   | 1987 | 15   | 4.2       | 1.32 | 40      | 4.2       | 1.25 |
|   | 1986 | 14   | 5.1       | 1.54 | 30      | 4.4       | 1.35 |
|   | 1985 | 11   | 4.4       | 1.12 | 10      | 4.3       | 1.06 |
| Fledge Rate <sup>c</sup>                      | 1990 | 15   | 3.7       | 1.91 | 30      | 3.0       | 2.17 |
|   | 1989 | 20   | 0.8       | 1.45 | 50      | 0.9       | 1.73 |
|   | 1988 | 16   | 4.3       | 1.49 | 37      | 3.3       | 2.14 |
|   | 1987 | 14   | 3.1       | 1.99 | 39      | 3.1       | 1.85 |
|   | 1986 | 14   | 1.3       | 2.27 | 27      | 1.2       | 2.00 |
|   | 1985 | 10   | 3.6       | 0.84 | 7       | 2.6       | 1.90 |
| Test of Frequency of Clutch Size <sup>d</sup> |      | G    | df        | P    |         |           |      |
|   | 1990 | 2.6  | 2         | >0.1 |         |           |      |
|   | 1989 | 1.5  | 2         | >0.1 |         |           |      |
|   | 1988 | 0.3  | 2         | >0.3 |         |           |      |
|   | 1987 | 2.6  | 2         | >0.1 |         |           |      |
|   | 1986 | 3.3  | 4         | >0.3 |         |           |      |
|   | 1985 | 5.4  | 3         | >0.1 |         |           |      |

<sup>a</sup> Clutch size is the maximum number of eggs laid in a nest.

<sup>b</sup> Hatch rate is the number of eggs which hatch of those available to hatch, not always the maximum number of eggs in the nest due to occasional predation.

<sup>c</sup> Fledge rate is the number of young that fledge from the eggs which hatch, and only includes those nests which were followed to completion.

<sup>d</sup> Categories of clutch size with fewer than 5 nests were not included.

# **SMALL MAMMALS AND NESTING BIRDS 1990 ANNUAL REPORT**

Table 11. Likelihood to hatch and fledge for tree swallows for 1985 through 1990. Data are from the Pirlot Road test plot and Tachycineta Meadows control plot. Overall comparisons were made using the G test of independence (df=11).

| ** HATCHING SUCCESS **        |         |        |            |            |
|-------------------------------|---------|--------|------------|------------|
| Year                          | Plot    | Hatch  | Not Hatch  | % Hatching |
| 1990                          | Test    | 122    | 7          | 94.6       |
|                               | Control | 203    | 22         | 90.2       |
| 1989                          | Test    | 85     | 17         | 83.3       |
|                               | Control | 216    | 43         | 83.4       |
| 1988                          | Test    | 90     | 8          | 91.8       |
|                               | Control | 206    | 21         | 90.7       |
| 1987                          | Test    | 63     | 11         | 85.1       |
|                               | Control | 166    | 32         | 83.8       |
| 1986                          | Test    | 71     | 5          | 93.4       |
|                               | Control | 132    | 25         | 84.1       |
| 1985                          | Test    | 48     | 8          | 85.7       |
|                               | Control | 43     | 5          | 89.6       |
| Overall G = 27.70 P < 0.005   |         |        |            |            |
| ** FLEDGING SUCCESS **        |         |        |            |            |
| Year                          | Plot    | Fledge | Not Fledge | % Fledging |
| 1990                          | Test    | 56     | 17         | 76.7       |
|                               | Control | 89     | 60         | 59.7       |
| 1989                          | Test    | 15     | 70         | 17.6       |
|                               | Control | 47     | 165        | 22.2       |
| 1988                          | Test    | 69     | 12         | 85.2       |
|                               | Control | 123    | 55         | 69.1       |
| 1987                          | Test    | 44     | 17         | 72.1       |
|                               | Control | 122    | 39         | 75.8       |
| 1986                          | Test    | 18     | 53         | 25.4       |
|                               | Control | 32     | 86         | 27.1       |
| 1985                          | Test    | 36     | 7          | 83.7       |
|                               | Control | 18     | 13         | 58.1       |
| Overall G = 315.14 P < 0.0001 |         |        |            |            |

# SMALL MAMMALS AND NESTING BIRDS 1990 ANNUAL REPORT

Table 12. ANOVA for clutch size of tree swallows. Tested are the effects of PLOT (test and control), YEAR (1985 through 1990) and the interaction of PLOT and YEAR.

| SOURCE    | DF  | TYPE III SS | MS    | F    | P > F |
|-----------|-----|-------------|-------|------|-------|
| PLOT      | 1   | 0.188       | 0.188 | 0.26 | 0.610 |
| YEAR      | 5   | 3.781       | 0.756 | 1.05 | 0.390 |
| PLOT*YEAR | 5   | 9.535       | 1.907 | 2.64 | 0.023 |
| ERROR     | 454 | 327.745     | 0.722 |      |       |

Table 13. ANOVA for hatch success of tree swallows. Tested are the effects of PLOT (test and control), YEAR (1985 through 1990) and the interaction of PLOT and YEAR.

| SOURCE    | DF  | TYPE III SS | MS    | F    | P > F  |
|-----------|-----|-------------|-------|------|--------|
| PLOT      | 1   | 1.621       | 1.621 | 1.04 | 0.308  |
| YEAR      | 5   | 35.495      | 7.099 | 4.57 | 0.0005 |
| PLOT*YEAR | 5   | 3.636       | 0.727 | 0.47 | 0.800  |
| ERROR     | 310 | 481.589     | 1.554 |      |        |

Table 14. ANOVA for fledging success of tree swallows. Tested are the effects of PLOT (test and control), YEAR (1985 through 1990) and the interaction of PLOT and YEAR.

| SOURCE    | DF  | TYPE III SS | MS     | F     | P > F  |
|-----------|-----|-------------|--------|-------|--------|
| PLOT      | 1   | 9.737       | 9.737  | 2.75  | 0.098  |
| YEAR      | 5   | 343.255     | 68.651 | 19.41 | 0.0001 |
| PLOT*YEAR | 5   | 14.941      | 2.988  | 0.84  | 0.519  |
| ERROR     | 270 | 955.116     | 3.537  |       |        |

# SMALL MAMMALS AND NESTING BIRDS 1990 ANNUAL REPORT

Table 15. Exposure data and frequency of mortality of EGGS during 1990 calculated using the Mayfield method (Mayfield 1961, 1975). Data are pooled from three test and two control sites (see text) and were compared using G-tests (Sokal and Rohlf 1981).

|          | EGG EXPOSURE DAYS   |                  | %    |
|----------|---------------------|------------------|------|
|          | without mortalities | with mortalities |      |
| TEST     | 6619                | 145              | 2.14 |
| CONTROL  | 17071               | 259              | 1.49 |
| G=11.646 |                     |                  |      |
| P<0.001  |                     |                  |      |

Table 16. Exposure data and frequency of mortality of NESTLINGS during 1990 calculated using the Mayfield method (Mayfield 1961, 1975). Data are pooled from three test and two control sites (see text) and were compared using G-tests (Sokal and Rohlf 1981).

|          | NESTLING EXPOSURE DAYS |                  | %    |
|----------|------------------------|------------------|------|
|          | without mortalities    | with mortalities |      |
| TEST     | 5017                   | 108              | 2.11 |
| CONTROL  | 14095                  | 186              | 1.30 |
| G=15.581 |                        |                  |      |
| P<0.001  |                        |                  |      |

# SMALL MAMMALS AND NESTING BIRDS 1990 ANNUAL REPORT

Table 17. Exposure data and frequency of total nest failure for OVERALL NESTS during 1990 calculated using the Mayfield method (Mayfield 1961, 1975). Data are pooled from three test and two control sites (see text) and were compared using G-tests (Sokal and Rohlf 1981).

|         | NEST EXPOSURE DAYS    |                    |      |
|---------|-----------------------|--------------------|------|
|         | without nest failures | with nest failures | %    |
| TEST    | 2727                  | 37                 | 1.34 |
| CONTROL | 7242                  | 61                 | 0.84 |
| G=5.375 |                       |                    |      |
| P<0.025 |                       |                    |      |

Table 18. Exposure data and frequency of total nest failure during the INCUBATION PHASE during 1990 calculated using the Mayfield method (Mayfield 1961, 1975). Data are pooled from three test and two control sites (see text) and were compared using G-tests (Sokal and Rohlf 1981).

|         | INCUBATION PHASE<br>NEST EXPOSURE DAYS |                    |      |
|---------|--|--------------------|------|
|         | without nest failures                  | with nest failures | %    |
| TEST    | 1467                                   | 21                 | 1.41 |
| CONTROL | 3843                                   | 35                 | 0.90 |
| G=2.508 |  |                    |      |
| P>0.1   |  |                    |      |



# SMALL MAMMALS AND NESTING BIRDS 1990 ANNUAL REPORT

Table 19. Exposure data and frequency of total nest failure during the NESTLING PHASE during 1990 calculated using the Mayfield method (Mayfield 1961, 1975). Data are pooled from three test and two control sites (see text) and were compared using G-tests (Sokal and Rohlf 1981).

|         | NESTLING PHASE<br>NEST EXPOSURE DAYS |                    |  | %    |
|---------|--------------------------------------|--------------------|--|------|
|         | without nest failures                | with nest failures |  |      |
| TEST    | 1260                                 | 16                 |  | 1.25 |
| CONTROL | 3399                                 | 26                 |  | 0.76 |
| G=2.361 |                                      |                    |  |      |
| P>0.1   |                                      |                    |  |      |

Table 20. Age in days at landmark events of eye opening and primary feather eruption in 1986 through 1990. Data are from the Pirlot Road test plot and Tachycineta Meadows control plot. Sample sizes are numbers of individual young. Day of hatching is defined as day zero.

| Year | Plot    | <u>Eye Opening</u> |           |      | <u>Primary Eruption</u> |           |      |
|------|---------|--------------------|-----------|------|-------------------------|-----------|------|
|      |         | n                  | $\bar{X}$ | SD   | n                       | $\bar{X}$ | SD   |
| 1990 | Test    | 64                 | 6.0       | 1.29 | 64                      | 7.7       | 1.25 |
|      | Control | 73                 | 6.4       | 1.44 | 73                      | 7.5       | 1.05 |
| 1989 | Test    | 25                 | 8.6       | 1.16 | 25                      | 9.1       | 1.69 |
|      | Control | 32                 | 7.8       | 0.93 | 32                      | 9.6       | 1.06 |
| 1988 | Test    | 76                 | 7.3       | 1.36 | 76                      | 8.2       | 1.21 |
|      | Control | 74                 | 6.7       | 1.38 | 74                      | 8.8       | 1.25 |
| 1987 | Test    | 44                 | 7.4       | 1.84 | 44                      | 8.5       | 1.13 |
|      | Control | 66                 | 6.7       | 1.48 | 66                      | 8.5       | 1.40 |
| 1986 | Test    | 18                 | 5.1       | 1.02 | 18                      | 8.8       | 1.11 |
|      | Control | 42                 | 6.0       | 0.73 | 42                      | 9.1       | 1.52 |

# SMALL MAMMALS AND NESTING BIRDS 1990 ANNUAL REPORT

Table 21. Nested ANOVA for age of eye opening in tree swallows. Tested are the effects of PLOT (test or control), and nests (NEST) within a plot (PLOT) for 1986 through 1990. The error term for PLOT effect is NEST(PLOT) mean square error.

| YEAR | SOURCE     | DF  | TYPE III SS | MS     | F    | P > F  |
|------|------------|-----|-------------|--------|------|--------|
| 1990 | PLOT       | 1   | 6.601       | 6.601  | 1.36 | 0.253  |
|      | NEST(PLOT) | 27  | 130.849     | 4.846  | 4.22 | 0.0001 |
|      | ERROR      | 108 | 123.917     | 1.147  |      |        |
| 1989 | PLOT       | 1   | 5.277       | 5.227  | 2.10 | 0.166  |
|      | NEST(PLOT) | 16  | 40.113      | 2.507  | 5.05 | 0.0001 |
|      | ERROR      | 39  | 19.379      | 0.497  |      |        |
| 1988 | PLOT       | 1   | 10.654      | 10.654 | 1.54 | 0.225  |
|      | NEST(PLOT) | 28  | 194.146     | 6.934  | 9.90 | 0.0001 |
|      | ERROR      | 120 | 84.050      | 0.700  |      |        |
| 1987 | PLOT       | 1   | 9.742       | 9.742  | 1.13 | 0.298  |
|      | NEST(PLOT) | 24  | 206.892     | 8.621  | 9.12 | 0.0001 |
|      | ERROR      | 84  | 79.433      | 0.946  |      |        |
| 1986 | PLOT       | 1   | 3.806       | 3.806  | 2.76 | 0.123  |
|      | NEST(PLOT) | 12  | 16.566      | 1.380  | 2.75 | 0.007  |
|      | ERROR      | 46  | 23.117      | 0.502  |      |        |

# SMALL MAMMALS AND NESTING BIRDS 1990 ANNUAL REPORT

Table 22. Nested ANOVA for primary feather eruption in tree swallows. Tested are the effects of PLOT (test or control), and nests (NEST) within a plot (PLOT) for 1986 through 1990. The error term for PLOT effect is NEST(PLOT) mean square error.

| YEAR | SOURCE     | DF  | TYPE III SS | MS     | F     | P > F  |
|------|------------|-----|-------------|--------|-------|--------|
| 1990 | PLOT       | 1   | 1.170       | 1.170  | 0.24  | 0.631  |
|      | NEST(PLOT) | 27  | 133.762     | 4.954  | 12.00 | 0.0001 |
|      | ERROR      | 108 | 44.583      | 0.413  |       |        |
| 1989 | PLOT       | 1   | 1.523       | 1.523  | 0.33  | 0.575  |
|      | NEST(PLOT) | 16  | 74.545      | 4.659  | 6.40  | 0.0001 |
|      | ERROR      | 39  | 28.413      | 0.729  |       |        |
| 1988 | PLOT       | 1   | 15.319      | 15.319 | 2.66  | 0.114  |
|      | NEST(PLOT) | 28  | 161.410     | 5.765  | 11.10 | 0.0001 |
|      | ERROR      | 120 | 62.317      | 0.519  |       |        |
| 1987 | PLOT       | 1   | 0.038       | 0.038  | 0.01  | 0.938  |
|      | NEST(PLOT) | 24  | 147.644     | 6.152  | 15.27 | 0.0001 |
|      | ERROR      | 84  | 33.833      | 0.403  |       |        |
| 1986 | PLOT       | 1   | 0.460       | 0.460  | 0.07  | 0.797  |
|      | NEST(PLOT) | 12  | 80.071      | 6.673  | 8.48  | 0.0001 |
|      | ERROR      | 46  | 36.183      | 0.787  |       |        |

# SMALL MAMMALS AND NESTING BIRDS 1990 ANNUAL REPORT

Table 23. Detectable differences and power for tree swallow fecundity variables: clutch size, hatch success and fledging success for data combined for 1985-1990. N = average number of nests per treatment per year for test or control. Detectable differences presented in units of variable with % of grand mean following in parentheses.

| Variable                     | N  | Actual<br>Detectable<br>Difference (%) | Actual<br>Power | Detectable<br>Difference at 70%<br>Power (%) |
|------------------------------|----|--|-----------------|--|
| Clutch size<br>eggs(%)       | 39 | .17 (3.0)                              | <.30            | .50(9.0)                                     |
| Hatch success<br>eggs(%)     | 26 | .07 (1.0)                              | <.30            | .90(18.0)                                    |
| Fledging success<br>young(%) | 23 | .73 (22.0)                             | <.30            | 1.40(42.0)                                   |

Table 24. Detectable differences and power for tree swallow landmark events; eye opening and feather eruption, for years 1986 through 1990. N = number of nests per treatment for test or control. Differences presented in days with % of grand mean following.

| Variable                       | Year | N  | Actual<br>Detectable<br>Difference(%) | Actual<br>Power | Detectable<br>Difference at 70%<br>Power (%) |
|--------------------------------|------|----|---------------------------------------|-----------------|--|
| Eye opening<br>days(%)         | 1990 | 13 | .52(8.4)                              | <.30            | 2.20(35.4)                                   |
|                                | 1989 | 8  | .83(10.1)                             | <.30            | 2.08(25.5)                                   |
|                                | 1988 | 14 | .73(10.4)                             | <.30            | 2.55(36.4)                                   |
|                                | 1987 | 12 | .43(6.2)                              | <.30            | 3.15(45.1)                                   |
|                                | 1986 | 6  | .90(15.7)                             | <.30            | 1.84(32.1)                                   |
| Feather<br>eruption<br>days(%) | 1990 | 13 | .763(10.1)                            | <.30            | 2.25(29.6)                                   |
|                                | 1989 | 8  | .885(9.4)                             | <.30            | 2.85(30.4)                                   |
|                                | 1988 | 14 | 1.168(13.7)                           | <.30            | 2.35(27.6)                                   |
|                                | 1987 | 12 | 1.009(11.9)                           | <.30            | 2.65(31.2)                                   |
|                                | 1986 | 6  | 1.439(16.0)                           | <.30            | 4.05(45.0)                                   |

# SMALL MAMMALS AND NESTING BIRDS 1990 ANNUAL REPORT

Table 25. Nested ANOVA for weight growth constant for nestling tree swallows. Tested are the effects of PLOT (test or control), and nests (NEST) within a plot (PLOT) for 1985 through 1990. The error term for PLOT effect is NEST(PLOT) mean square error.

| YEAR | SOURCE     | DF  | TYPE III SS | MS      | F     | P > F               |
|------|------------|-----|-------------|---------|-------|---------------------|
| 1990 | PLOT       | 1   | 0.0087      | 0.0087  | 0.55  | 0.4637              |
|      | NEST(PLOT) | 26  | 0.4095      | 0.0157  | 9.74  | 0.0001              |
|      | ERROR      | 92  | 0.1487      | 0.0016  |       |                     |
| 1989 | PLOT       | 1   | 0.00003     | 0.00003 | 0.00  | 0.957               |
|      | NEST(PLOT) | 13  | 0.1309      | 0.0101  | 7.84  | 0.0001              |
|      | ERROR      | 36  | 0.0462      | 0.0013  |       |                     |
| 1988 | PLOT       | 1   | 0.0056      | 0.0056  | 0.51  | 0.4834              |
|      | NEST(PLOT) | 26  | 0.2890      | 0.0111  | 6.24  | 0.0001              |
|      | ERROR      | 101 | 0.1800      | 0.0018  |       |                     |
| 1987 | PLOT       | 1   | 0.0320      | 0.0320  | 2.78  | 0.1088 <sup>a</sup> |
|      | NEST(PLOT) | 23  | 0.2646      | 0.0115  | 5.74  | 0.0001              |
|      | ERROR      | 78  | 0.1563      | 0.0020  |       |                     |
| 1986 | PLOT       | 1   | 0.0002      | 0.0002  | 0.01  | 0.9196              |
|      | NEST(PLOT) | 13  | 0.2976      | 0.0229  | 17.95 | 0.0001              |
|      | ERROR      | 48  | 0.0612      | 0.0013  |       |                     |
| 1985 | PLOT       | 1   | 0.0574      | 0.0574  | 3.50  | 0.0685 <sup>a</sup> |
|      | NEST(PLOT) | 42  | 0.6900      | 0.0164  | 12.48 | 0.0001              |
|      | ERROR      | 119 | 0.1567      | 0.0013  |       |                     |

<sup>a</sup> Plot effect approached significance.

# SMALL MAMMALS AND NESTING BIRDS 1990 ANNUAL REPORT

Table 26. Nested ANOVA for the inflection point of weight increase in tree swallows. Tested are the effects of PLOT (test vs control), and nests (NEST) within a plot for 1985 through 1990. The error term for PLOT effect is NEST(PLOT) mean square error.

| YEAR | SOURCE     | DF  | TYPE III SS | MS      | F     | P > F               |
|------|------------|-----|-------------|---------|-------|---------------------|
| 1990 | PLOT       | 1   | 0.6249      | 0.6249  | 0.18  | 0.6725              |
|      | NEST(PLOT) | 26  | 88.8915     | 3.4189  | 9.43  | 0.0001              |
|      | ERROR      | 92  | 33.3400     | 0.3624  |       |                     |
| 1989 | PLOT       | 1   | 8.9688      | 8.9688  | 4.39  | 0.0562 <sup>a</sup> |
|      | NEST(PLOT) | 13  | 26.5425     | 2.0417  | 5.98  | 0.0001              |
|      | ERROR      | 36  | 12.2895     | 0.3414  |       |                     |
| 1988 | PLOT       | 1   | 0.0122      | 0.0122  | 0.01  | 0.9288              |
|      | NEST(PLOT) | 26  | 38.8471     | 1.4941  | 4.91  | 0.0001              |
|      | ERROR      | 101 | 30.7272     | 0.3042  |       |                     |
| 1987 | PLOT       | 1   | 3.9591      | 3.9591  | 1.26  | 0.2726              |
|      | NEST(PLOT) | 23  | 72.0791     | 3.1339  | 8.33  | 0.0001              |
|      | ERROR      | 78  | 29.3285     | 0.3760  |       |                     |
| 1986 | PLOT       | 1   | 0.0198      | 0.0198  | 0.01  | 0.9419              |
|      | NEST(PLOT) | 13  | 46.5682     | 3.5822  | 13.55 | 0.0001              |
|      | ERROR      | 48  | 12.6856     | 0.2643  |       |                     |
| 1985 | PLOT       | 1   | 16.8483     | 16.8483 | 6.29  | 0.0161 <sup>b</sup> |
|      | NEST(PLOT) | 42  | 112.4841    | 2.6782  | 7.61  | 0.0001              |
|      | ERROR      | 119 | 41.8896     | 0.3520  |       |                     |

<sup>a</sup> Plot effect approached significance.

<sup>b</sup> Plot effect reached significance.

# SMALL MAMMALS AND NESTING BIRDS 1990 ANNUAL REPORT

Table 27. Nested ANOVA for the slope from linear regression of weight increase in nestling tree swallows between ages 3 and 11 days. Tested are the effects of PLOT (test vs. control), and nests (NEST) within a plot for 1985 through 1990. The error term for PLOT effect is NEST(PLOT) mean square error.

| YEAR | SOURCE     | DF  | TYPE III SS | MS    | F     | P > F  |
|------|------------|-----|-------------|-------|-------|--------|
| 1990 | PLOT       | 1   | 0.105       | 0.105 | 0.270 | 0.608  |
|      | NEST(PLOT) | 24  | 9.312       | 0.388 | 9.309 | 0.0001 |
|      | ERROR      | 83  | 3.459       | 0.042 |       |        |
| 1989 | PLOT       | 1   | 0.175       | 0.174 | 0.349 | 0.563  |
|      | NEST(PLOT) | 16  | 8.012       | 0.501 | 8.117 | 0.0001 |
|      | ERROR      | 36  | 2.221       | 0.062 |       |        |
| 1988 | PLOT       | 1   | 0.154       | 0.154 | 0.340 | 0.564  |
|      | NEST(PLOT) | 27  | 12.210      | 0.452 | 7.261 | 0.0001 |
|      | ERROR      | 100 | 6.229       | 0.062 |       |        |
| 1987 | PLOT       | 1   | 0.001       | 0.001 | 0.005 | 0.943  |
|      | NEST(PLOT) | 23  | 4.309       | 0.187 | 3.134 | 0.0001 |
|      | ERROR      | 79  | 4.722       | 0.060 |       |        |
| 1986 | PLOT       | 1   | 0.027       | 0.027 | 0.179 | 0.679  |
|      | NEST(PLOT) | 14  | 2.087       | 0.149 | 3.029 | 0.002  |
|      | ERROR      | 48  | 2.362       | 0.049 |       |        |
| 1985 | PLOT       | 1   | 0.005       | 0.005 | 0.017 | 0.896  |
|      | NEST(PLOT) | 39  | 10.817      | 0.277 | 7.041 | 0.0001 |
|      | ERROR      | 120 | 4.727       | 0.039 |       |        |

# **SMALL MAMMALS AND NESTING BIRDS 1990 ANNUAL REPORT**

Table 28. Nested ANOVA for the maximum weight attained by nestling tree swallows. Tested are the effects of PLOT (test vs. control), and nests (NEST) within a plot for 1985 through 1990. The error term for PLOT effect is NEST(PLOT) mean square error.

| YEAR | SOURCE     | DF  | TYPE III SS | MS     | F     | P > F  |
|------|------------|-----|-------------|--------|-------|--------|
| 1990 | PLOT       | 1   | 1.752       | 1.752  | 0.156 | 0.698  |
|      | NEST(PLOT) | 19  | 213.743     | 11.249 | 7.719 | 0.0001 |
|      | ERROR      | 67  | 97.644      | 1.457  |       |        |
| 1989 | PLOT       | 1   | 7.473       | 7.473  | 1.641 | 0.221  |
|      | NEST(PLOT) | 14  | 63.743      | 4.553  | 3.375 | 0.001  |
|      | ERROR      | 38  | 51.269      | 1.349  |       |        |
| 1988 | PLOT       | 1   | 3.041       | 3.041  | 0.299 | 0.589  |
|      | NEST(PLOT) | 27  | 274.211     | 10.156 | 5.651 | 0.0001 |
|      | ERROR      | 102 | 183.314     | 1.797  |       |        |
| 1987 | PLOT       | 1   | 5.043       | 5.043  | 0.631 | 0.435  |
|      | NEST(PLOT) | 22  | 175.769     | 7.989  | 4.331 | 0.0001 |
|      | ERROR      | 74  | 132.822     | 1.845  |       |        |
| 1986 | PLOT       | 1   | 7.657       | 7.657  | 1.522 | 0.241  |
|      | NEST(PLOT) | 12  | 60.377      | 5.031  | 4.024 | 0.000  |
|      | ERROR      | 44  | 55.019      | 1.250  |       |        |
| 1985 | PLOT       | 1   | 0.105       | 0.105  | 0.011 | 0.919  |
|      | NEST(PLOT) | 37  | 367.487     | 9.932  | 3.088 | 0.000  |
|      | ERROR      | 98  | 315.163     | 3.216  |       |        |



# SMALL MAMMALS AND NESTING BIRDS 1990 ANNUAL REPORT

Table 29. Nested ANOVA for the age of maximum weight attained by tree swallow nestlings. Tested are the effects of PLOT (test vs. control), and nests (NEST) within a plot for 1985 through 1990. The error term for PLOT effect is NEST(PLOT) mean square error.

| YEAR | SOURCE     | DF  | TYPE II SS | MS     | F     | P > F              |
|------|------------|-----|------------|--------|-------|--------------------|
| 1990 | PLOT       | 1   | 13.639     | 13.639 | 3.783 | 0.067 <sup>a</sup> |
|      | NEST(PLOT) | 19  | 68.509     | 3.606  | 2.795 | 0.001              |
|      | ERROR      | 108 | 114.750    | 1.063  |       |                    |
| 1989 | PLOT       | 1   | 4.029      | 4.029  | 0.713 | 0.412              |
|      | NEST(PLOT) | 14  | 79.063     | 5.647  | 3.313 | 0.002              |
|      | ERROR      | 38  | 64.771     | 1.788  |       |                    |
| 1988 | PLOT       | 1   | 11.147     | 11.147 | 1.112 | 0.301              |
|      | NEST(PLOT) | 27  | 270.558    | 10.021 | 5.603 | 0.0001             |
|      | ERROR      | 102 | 182.417    | 1.788  |       |                    |
| 1987 | PLOT       | 1   | 10.556     | 10.556 | 1.726 | 0.202              |
|      | NEST(PLOT) | 22  | 134.545    | 6.116  | 2.843 | 0.0001             |
|      | ERROR      | 72  | 154.867    | 2.151  |       |                    |
| 1986 | PLOT       | 1   | 0.004      | 0.004  | 0.001 | 0.980              |
|      | NEST(PLOT) | 12  | 72.853     | 6.071  | 3.956 | 0.0001             |
|      | ERROR      | 44  | 67.517     | 1.534  |       |                    |
| 1985 | PLOT       | 1   | 35.104     | 35.104 | 6.289 | 0.017 <sup>b</sup> |
|      | NEST(PLOT) | 37  | 206.537    | 5.582  | 2.375 | 0.0001             |
|      | ERROR      | 98  | 203.350    | 2.351  |       |                    |

<sup>a</sup> Plot effect approached significance.

<sup>b</sup> Plot effect reached significance.

# SMALL MAMMALS AND NESTING BIRDS 1990 ANNUAL REPORT

Table 30. Nested ANOVA for tarsus growth constant in tree swallows. Tested are the effects of PLOT (test vs control) and nests (NEST) within a plot for 1985 through 1990. The error term for PLOT effect is NEST(PLOT) mean square error.

| YEAR | SOURCE     | DF  | TYPE III SS | MS     | F     | P > F               |
|------|------------|-----|-------------|--------|-------|---------------------|
| 1990 | PLOT       | 1   | 0.0080      | 0.0080 | 0.50  | 0.4875              |
|      | NEST(PLOT) | 27  | 0.4332      | 0.0160 | 9.23  | 0.0001              |
|      | ERROR      | 105 | 0.1826      | 0.0017 |       |                     |
| 1989 | PLOT       | 1   | 0.0612      | 0.0612 | 4.26  | 0.0596 <sup>a</sup> |
|      | NEST(PLOT) | 13  | 0.1868      | 0.0144 | 18.76 | 0.0001              |
|      | ERROR      | 38  | 0.0291      | 0.0008 |       |                     |
| 1988 | PLOT       | 1   | 0.0068      | 0.0068 | 0.18  | 0.6710              |
|      | NEST(PLOT) | 27  | 0.9939      | 0.0368 | 3.81  | 0.0001              |
|      | ERROR      | 115 | 1.1107      | 0.0097 |       |                     |
| 1987 | PLOT       | 1   | 0.0477      | 0.0477 | 2.32  | 0.1406              |
|      | NEST(PLOT) | 24  | 0.4927      | 0.0205 | 4.96  | 0.0001              |
|      | ERROR      | 85  | 0.3520      | 0.0041 |       |                     |
| 1986 | PLOT       | 1   | 0.0001      | 0.0001 | 0.01  | 0.9387              |
|      | NEST(PLOT) | 13  | 0.2020      | 0.0155 | 4.27  | 0.0001              |
|      | ERROR      | 48  | 0.1746      | 0.0036 |       |                     |
| 1985 | PLOT       | 1   | 0.0503      | 0.0503 | 2.46  | 0.1242              |
|      | NEST(PLOT) | 43  | 0.8796      | 0.0205 | 4.14  | 0.0001              |
|      | ERROR      | 119 | 0.5878      | 0.0049 |       |                     |

<sup>a</sup> Plot effect approached significance.

# SMALL MAMMALS AND NESTING BIRDS 1990 ANNUAL REPORT

Table 31. Nested ANOVA for the inflection point of tarsus growth in tree swallows. Tested are the effects of PLOT (test vs control), and nests (NEST) within a plot for 1985 through 1990. The error term for PLOT effect is NEST(PLOT) mean square error.

| YEAR | SOURCE     | DF  | TYPE III SS | MS     | F    | P > F               |
|------|------------|-----|-------------|--------|------|---------------------|
| 1990 | PLOT       | 1   | 0.5446      | 0.5446 | 0.61 | 0.4431              |
|      | NEST(PLOT) | 27  | 24.2747     | 0.8991 | 5.56 | 0.0001              |
|      | ERROR      | 105 | 16.9844     | 0.1618 |      |                     |
| 1989 | PLOT       | 1   | 9.8787      | 9.8787 | 5.97 | 0.0296 <sup>a</sup> |
|      | NEST(PLOT) | 13  | 21.5293     | 1.6561 | 8.10 | 0.0001              |
|      | ERROR      | 38  | 7.7672      | 0.2044 |      |                     |
| 1988 | PLOT       | 1   | 0.7450      | 0.7450 | 0.71 | 0.4078              |
|      | NEST(PLOT) | 27  | 28.4436     | 1.0535 | 5.32 | 0.0001              |
|      | ERROR      | 115 | 22.7629     | 0.1979 |      |                     |
| 1987 | PLOT       | 1   | 0.6721      | 0.6721 | 0.23 | 0.6387              |
|      | NEST(PLOT) | 24  | 71.3462     | 2.9728 | 9.39 | 0.0001              |
|      | ERROR      | 85  | 26.8960     | 0.3164 |      |                     |
| 1986 | PIOT       | 1   | 0.5755      | 0.5755 | 0.34 | 0.5679              |
|      | NEST(PLOT) | 13  | 21.7884     | 1.6760 | 8.15 | 0.0001              |
|      | ERROR      | 48  | 9.8715      | 0.2057 |      |                     |
| 1985 | PLOT       | 1   | 3.8980      | 3.8980 | 3.20 | 0.0807              |
|      | NEST(PLOT) | 43  | 52.3968     | 1.2185 | 5.15 | 0.0001              |
|      | ERROR      | 119 | 28.1779     | 0.2368 |      |                     |

<sup>a</sup> Plot effect approached significance.

# SMALL MAMMALS AND NESTING BIRDS 1990 ANNUAL REPORT

Table 32. Nested ANOVA for the slope of the linear regression of tarsus growth (between the ages of 3DPH and 11 DPH) in nestling tree swallows. Tested are the effects of PLOT (test vs. control), and nests (NEST) within a plot for 1985 through 1990. The error term for PLOT effect is NEST(PLOT) mean square error.

| YEAR | SOURCE     | DF | TYPE III SS | MS    | F     | P > F              |
|------|------------|----|-------------|-------|-------|--------------------|
| 1990 | PLOT       | 1  | 0.000       | 0.000 | 0.006 | 0.941              |
|      | NEST(PLOT) | 24 | 1.117       | 0.047 | 3.237 | 0.0001             |
|      | ERROR      | 48 | 0.690       | 0.014 |       |                    |
| 1989 | PLOT       | 1  | 0.151       | 0.151 | 4.293 | 0.060 <sup>a</sup> |
|      | NEST(PLOT) | 12 | 0.422       | 0.035 | 3.465 | 0.005              |
|      | ERROR      | 32 | 0.304       | 0.009 |       |                    |
| 1988 | PLOT       | 1  | 0.020       | 0.020 | 0.415 | 0.529              |
|      | NEST(PLOT) | 15 | 0.709       | 0.047 | 2.908 | 0.010              |
|      | ERROR      | 23 | 0.374       | 0.016 |       |                    |
| 1987 | PLOT       | 1  | 0.005       | 0.005 | 0.063 | 0.807              |
|      | NEST(PLOT) | 12 | 0.981       | 0.082 | 3.117 | 0.020              |
|      | ERROR      | 15 | 0.393       | 0.026 |       |                    |
| 1986 | PLOT       | 1  | 0.024       | 0.024 | 0.917 | 0.359              |
|      | NEST(PLOT) | 11 | 0.291       | 0.026 | 2.627 | 0.0001             |
|      | ERROR      | 23 | 0.232       | 0.010 |       |                    |
| 1985 | PLOT       | 1  | 0.002       | 0.002 | 0.042 | 0.839              |
|      | NEST(PLOT) | 34 | 1.586       | 0.047 | 4.949 | 0.0001             |
|      | ERROR      | 60 | 0.555       | 0.009 |       |                    |

<sup>a</sup> Plot effect approached significance.

# SMALL MAMMALS AND NESTING BIRDS 1990 ANNUAL REPORT

Table 33. Nested ANOVA for the maximum length of tarsus attained by nestling tree swallows. Tested are the effects of PLOT (test vs. control), and nests (NEST) within a plot for 1985 through 1990. The error term for PLOT effect is NEST(PLOT) mean square error.

| YEAR | SOURCE     | DF  | TYPE III SS | MS    | F     | P > F  |
|------|------------|-----|-------------|-------|-------|--------|
| 1990 | PLOT       | 1   | 0.107       | 0.107 | 0.107 | 0.684  |
|      | NEST(PLOT) | 19  | 11.877      | 0.625 | 2.691 | 0.002  |
|      | ERROR      | 67  | 15.562      | 0.232 |       |        |
| 1989 | PLOT       | 1   | 0.009       | 0.009 | 0.035 | 0.854  |
|      | NEST(PLOT) | 14  | 3.506       | 0.250 | 2.494 | 0.013  |
|      | ERROR      | 38  | 3.815       | 0.100 |       |        |
| 1988 | PLOT       | 1   | 0.007       | 0.007 | 0.017 | 0.899  |
|      | NEST(PLOT) | 27  | 11.184      | 0.414 | 4.467 | 0.000  |
|      | ERROR      | 102 | 9.457       | 0.093 |       |        |
| 1987 | PLOT       | 1   | 0.035       | 0.035 | 0.104 | 0.750  |
|      | NEST(PLOT) | 22  | 7.453       | 0.339 | 0.934 | 0.554  |
|      | ERROR      | 72  | 26.128      | 0.363 |       |        |
| 1986 | PLOT       | 1   | 0.456       | 0.456 | 1.071 | 0.321  |
|      | NEST(PLOT) | 12  | 5.108       | 0.426 | 4.412 | 0.0001 |
|      | ERROR      | 44  | 4.245       | 0.096 |       |        |
| 1985 | PLOT       | 1   | 0.400       | 0.400 | 0.729 | 0.399  |
|      | NEST(PLOT) | 37  | 20.320      | 0.549 | 2.215 | 0.001  |
|      | ERROR      | 98  | 24.294      | 0.248 |       |        |

# SMALL MAMMALS AND NESTING BIRDS 1990 ANNUAL REPORT

Table 34. Nested ANOVA for the age of maximum length of tarsus attained by tree swallow nestlings. Tested are the effects of PLOT (test vs. control), and nests (NEST) within a plot for 1985 through 1990. The error term for PLOT effect is NEST(PLOT) mean square error.

| YEAR | SOURCE     | DF  | TYPE II SS | MS      | F      | P > F              |
|------|------------|-----|------------|---------|--------|--------------------|
| 1990 | PLOT       | 1   | 27.252     | 27.252  | 3.163  | 0.091 <sup>a</sup> |
|      | NEST(PLOT) | 19  | 163.729    | 8.617   | 1.652  | 0.069              |
|      | ERROR      | 67  | 349.575    | 5.218   |        |                    |
| 1989 | PLOT       | 1   | 4.871      | 4.871   | 0.611  | 0.448              |
|      | NEST(PLOT) | 14  | 111.696    | 7.978   | 6.667  | 0.0001             |
|      | ERROR      | 38  | 45.471     | 1.197   |        |                    |
| 1988 | PLOT       | 1   | 0.890      | 0.890   | 0.129  | 0.722              |
|      | NEST(PLOT) | 27  | 186.429    | 6.905   | 1.282  | 0.188              |
|      | ERROR      | 102 | 550.317    | 5.395   |        |                    |
| 1987 | PLOT       | 1   | 0.514      | 0.514   | 0.038  | 0.848              |
|      | NEST(PLOT) | 22  | 298.908    | 13.587  | 2.884  | 0.0001             |
|      | ERROR      | 74  | 341.867    | 4.620   |        |                    |
| 1986 | PLOT       | 1   | 104.470    | 104.470 | 10.651 | 0.007 <sup>b</sup> |
|      | NEST(PLOT) | 12  | 117.703    | 9.809   | 1.783  | 0.082              |
|      | ERROR      | 44  | 242.117    | 5.503   |        |                    |
| 1985 | PLOT       | 1   | 0.321      | 0.321   | 0.037  | 0.848              |
|      | NEST(PLOT) | 37  | 319.914    | 8.646   | 2.301  | 0.001              |
|      | ERROR      | 98  | 368.217    | 3.757   |        |                    |

<sup>a</sup> Plot effect approached significance.

<sup>b</sup> Plot effect reached significance.

# SMALL MAMMALS AND NESTING BIRDS 1990 ANNUAL REPORT

Table 35. Nested ANOVA for ulna growth constant in tree swallows.  
Tested are the effects of PLOT (test vs control), and nests (NEST) within a plot for 1985 through 1990. The error term for PLOT effect is NEST(PLOT) mean square error.

| YEAR | SOURCE     | DF  | TYPE III SS | MS     | F     | P > F  |
|------|------------|-----|-------------|--------|-------|--------|
| 1990 | PLOT       | 1   | 0.0002      | 0.0002 | 0.02  | 0.8890 |
|      | NEST(PLOT) | 26  | 0.3055      | 0.0117 | 20.07 | 0.0001 |
|      | ERROR      | 105 | 0.0615      | 0.0006 |       |        |
| 1989 | PLOT       | 1   | 0.0079      | 0.0079 | 1.18  | 0.2969 |
|      | NEST(PLOT) | 13  | 0.0870      | 0.0067 | 17.65 | 0.0001 |
|      | ERROR      | 38  | 0.0140      | 0.0004 |       |        |
| 1988 | PLOT       | 1   | 0.0003      | 0.0003 | 0.03  | 0.8683 |
|      | NEST(PLOT) | 27  | 0.2552      | 0.0095 | 11.08 | 0.0001 |
|      | ERROR      | 113 | 0.0964      | 0.0009 |       |        |
| 1987 | PLOT       | 1   | 0.0002      | 0.0002 | 0.03  | 0.8598 |
|      | NEST(PLOT) | 23  | 0.1747      | 0.0076 | 4.88  | 0.0001 |
|      | ERROR      | 78  | 0.1214      | 0.0016 |       |        |
| 1986 | PLOT       | 1   | 0.0002      | 0.0002 | 0.02  | 0.8890 |
|      | NEST(PLOT) | 13  | 0.1421      | 0.0109 | 25.23 | 0.0001 |
|      | ERROR      | 46  | 0.0199      | 0.0004 |       |        |
| 1985 | PLOT       | 1   | 0.0021      | 0.0021 | 0.23  | 0.6325 |
|      | NEST(PLOT) | 33  | 0.2946      | 0.0089 | 11.26 | 0.0001 |
|      | ERROR      | 78  | 0.0618      | 0.0008 |       |        |

# SMALL MAMMALS AND NESTING BIRDS 1990 ANNUAL REPORT

Table 36. Nested ANOVA for the inflection point of ulna growth in tree swallows. Tested are the effects of PLOT (test or control), and nests (NEST) within a plot for 1985 through 1990. The error term for PLOT effect is NEST(PLOT) mean square error.

| YEAR | SOURCE     | DF  | TYPE III SS | MS      | F     | P > F   |
|------|------------|-----|-------------|---------|-------|---------|
| 1990 | PLOT       | 1   | 0.1092      | 0.1092  | 0.04  | 0.8507  |
|      | NEST(PLOT) | 26  | 78.5723     | 3.0220  | 9.23  | 0.0001  |
|      | ERROR      | 105 | 34.3740     | 0.3274  |       |         |
| 1989 | PLOT       | 1   | 11.7471     | 11.7471 | 4.78  | 0.0476* |
|      | NEST(PLOT) | 13  | 31.9270     | 2.4559  | 8.11  | 0.0001  |
|      | ERROR      | 37  | 11.2054     | 0.3028  |       |         |
| 1988 | PLOT       | 1   | 0.2790      | 0.2790  | 0.14  | 0.7160  |
|      | NEST(PLOT) | 27  | 55.7286     | 2.0640  | 8.91  | 0.0001  |
|      | ERROR      | 113 | 26.1634     | 0.2315  |       |         |
| 1987 | PLOT       | 1   | 4.2878      | 4.2878  | 1.34  | 0.2581  |
|      | NEST(PLOT) | 23  | 73.3503     | 3.1891  | 11.46 | 0.0001  |
|      | ERROR      | 78  | 21.6979     | 0.2782  |       |         |
| 1986 | PLOT       | 1   | 0.8687      | 0.8687  | 0.47  | 0.5040  |
|      | NEST(PLOT) | 13  | 23.9146     | 1.8396  | 9.94  | 0.0001  |
|      | ERROR      | 46  | 8.5105      | 0.1850  |       |         |
| 1985 | PLOT       | 1   | 3.2694      | 3.2694  | 1.12  | 0.2976  |
|      | NEST(PLOT) | 33  | 96.3185     | 2.9187  | 14.62 | 0.0001  |
|      | ERROR      | 78  | 15.5741     | 0.1997  |       |         |

\* Plot effect reached significance.



# SMALL MAMMALS AND NESTING BIRDS 1990 ANNUAL REPORT

Table 37. Nested ANOVA for the slope of the linear regression of ulna growth (between the ages of 3 DPH and 11 DPH) in nestling tree swallows. Tested are the effects of PLOT (test vs. control), and nests (NEST) within a plot for 1985 through 1990. The error term for PLOT effect is NEST(PLOT) mean square error.

| YEAR | SOURCE     | DF  | TYPE III SS | MS    | F      | P > F              |
|------|------------|-----|-------------|-------|--------|--------------------|
| 1990 | PLOT       | 1   | 0.098       | 0.098 | 0.291  | 0.594              |
|      | NEST(PLOT) | 29  | 8.743       | 0.336 | 10.149 | 0.0001             |
|      | ERROR      | 83  | 2.750       | 0.033 |        |                    |
| 1989 | PLOT       | 1   | 1.054       | 1.054 | 4.966  | 0.039 <sup>a</sup> |
|      | NEST(PLOT) | 18  | 3.821       | 0.212 | 6.827  | 0.0001             |
|      | ERROR      | 34  | 1.057       | 0.031 |        |                    |
| 1988 | PLOT       | 1   | 0.058       | 0.058 | 0.600  | 0.446              |
|      | NEST(PLOT) | 24  | 2.335       | 0.097 | 2.682  | 0.0001             |
|      | ERROR      | 101 | 3.665       | 0.036 |        |                    |
| 1987 | PLOT       | 1   | 0.223       | 0.223 | 1.192  | 0.286              |
|      | NEST(PLOT) | 24  | 4.494       | 0.187 | 3.866  | 0.0001             |
|      | ERROR      | 78  | 3.778       | 0.048 |        |                    |
| 1986 | PLOT       | 1   | 0.197       | 0.197 | 3.585  | 0.085 <sup>b</sup> |
|      | NEST(PLOT) | 11  | 0.604       | 0.055 | 2.379  | 0.021              |
|      | ERROR      | 44  | 1.015       | 0.023 |        |                    |
| 1985 | PLOT       | 1   | 0.573       | 0.573 | 1.422  | 0.240              |
|      | NEST(PLOT) | 39  | 15.727      | 0.403 | 10.431 | 0.0001             |
|      | ERROR      | 101 | 3.905       | 0.039 |        |                    |

<sup>a</sup> Plot effect reached significance.

<sup>b</sup> Plot effect approached significance.

# SMALL MAMMALS AND NESTING BIRDS 1990 ANNUAL REPORT

Table 38. Nested ANOVA for the maximum length of ulna attained by nestling tree swallows. Tested are the effects of PLOT (test vs. control), and nests (NEST) within a plot for 1985 through 1990. The error term for PLOT effect is NEST(PLOT) mean square error.

| YEAR | SOURCE     | DF  | TYPE III SS | MS     | F     | P > F              |
|------|------------|-----|-------------|--------|-------|--------------------|
| 1990 | PLOT       | 1   | 0.177       | 0.177  | 2.227 | 0.639              |
|      | NEST(PLOT) | 19  | 14.769      | 0.779  | 1.463 | 0.129              |
|      | ERROR      | 108 | 71.700      | 0.664  |       |                    |
| 1989 | PLOT       | 1   | 0.694       | 0.694  | 0.598 | 0.452              |
|      | NEST(PLOT) | 14  | 16.247      | 1.160  | 5.069 | 0.0001             |
|      | ERROR      | 38  | 8.700       | 0.229  |       |                    |
| 1988 | PLOT       | 1   | 3.423       | 3.423  | 2.974 | 0.096 <sup>a</sup> |
|      | NEST(PLOT) | 27  | 31.085      | 1.151  | 2.399 | 0.001              |
|      | ERROR      | 102 | 48.954      | 0.480  |       |                    |
| 1987 | PLOT       | 1   | 9.016       | 9.016  | 4.942 | 0.037 <sup>b</sup> |
|      | NEST(PLOT) | 22  | 40.136      | 1.824  | 2.458 | 0.002              |
|      | ERROR      | 72  | 53.428      | 0.742  |       |                    |
| 1986 | PLOT       | 1   | 8.606       | 8.606  | 8.646 | 0.012 <sup>b</sup> |
|      | NEST(PLOT) | 12  | 11.944      | 0.995  | 3.299 | 0.002              |
|      | ERROR      | 44  | 13.275      | 0.302  |       |                    |
| 1985 | PLOT       | 1   | 6.460       | 6.460  | 0.477 | 0.494              |
|      | NEST(PLOT) | 37  | 500.884     | 13.537 | 4.980 | 0.0001             |
|      | ERROR      | 98  | 266.376     | 2.718  |       |                    |

<sup>a</sup> Plot effect approached significance.

<sup>b</sup> Plot effect reached significance.

# SMALL MAMMALS AND NESTING BIRDS 1990 ANNUAL REPORT

Table 39. Nested ANOVA for the age of maximum length of ulna attained by tree swallow nestlings. Tested are the effects of PLOT (test vs. control), and nests (NEST) within a plot for 1985 through 1990. The error term for PLOT effect is NEST(PLOT) mean square error.

| YEAR | SOURCE     | DF  | TYPE II SS | MS     | F      | P > F              |
|------|------------|-----|------------|--------|--------|--------------------|
| 1990 | PLOT       | 1   | 40.760     | 40.760 | 2.028  | 0.164              |
|      | NEST(PLOT) | 31  | 622.926    | 20.094 | 13.286 | 0.000              |
|      | ERROR      | 108 | 163.350    | 1.513  |        |                    |
| 1989 | PLOT       | 1   | 8.857      | 8.857  | 1.205  | 0.291              |
|      | NEST(PLOT) | 14  | 102.875    | 7.348  | 5.598  | 0.000              |
|      | ERROR      | 38  | 49.883     | 1.313  |        |                    |
| 1988 | PLOT       | 1   | 5.260      | 5.260  | 1.695  | 0.204              |
|      | NEST(PLOT) | 27  | 83.790     | 3.103  | 2.344  | 0.001              |
|      | ERROR      | 102 | 135.050    | 1.324  |        |                    |
| 1987 | PLOT       | 1   | 2.951      | 2.951  | 0.393  | 0.537              |
|      | NEST(PLOT) | 22  | 165.214    | 7.510  | 4.180  | 0.000              |
|      | ERROR      | 74  | 132.933    | 1.796  |        |                    |
| 1986 | PLOT       | 1   | 8.396      | 8.396  | 1.375  | 0.264              |
|      | NEST(PLOT) | 12  | 73.292     | 6.108  | 2.530  | 0.012              |
|      | ERROR      | 44  | 106.200    | 2.414  |        |                    |
| 1985 | PLOT       | 1   | 43.723     | 43.723 | 7.122  | 0.011 <sup>a</sup> |
|      | NEST(PLOT) | 38  | 233.302    | 6.140  | 2.514  | 0.000              |
|      | ERROR      | 99  | 241.783    | 2.442  |        |                    |

<sup>a</sup> Plot effect reached significance.

# SMALL MAMMALS AND NESTING BIRDS 1990 ANNUAL REPORT

Table 40. Nested ANOVA for wing growth in tree swallows. Tested are the effects of PLOT (test or control), and nests (NEST) within a plot for 1985 through 1990. The error term for PLOT effect is NEST(PLOT) mean square error.

| YEAR | SOURCE     | DF  | TYPE III SS | MS       | F     | P > F               |
|------|------------|-----|-------------|----------|-------|---------------------|
| 1990 | PLOT       | 1   | 0.0092      | 0.0092   | 3.25  | 0.0824 <sup>a</sup> |
|      | NEST(PLOT) | 27  | 0.0764      | 0.0028   | 38.35 | 0.0001              |
|      | ERROR      | 109 | 0.0080      | 0.00007  |       |                     |
| 1989 | PLOT       | 1   | 0.000009    | 0.000009 | 0.05  | 0.8328              |
|      | NEST(PLOT) | 13  | 0.0026      | 0.0002   | 7.18  | 0.0001              |
|      | ERROR      | 37  | 0.0010      | 0.00003  |       |                     |
| 1988 | PLOT       | 1   | 0.0001      | 0.0001   | 0.20  | 0.6614              |
|      | NEST(PLOT) | 27  | 0.0146      | 0.0005   | 5.86  | 0.0001              |
|      | ERROR      | 114 | 0.0105      | 0.00009  |       |                     |
| 1987 | PLOT       | 1   | 0.0005      | 0.0005   | 1.23  | 0.2796              |
|      | NEST(PLOT) | 22  | 0.0087      | 0.0004   | 4.59  | 0.0001              |
|      | ERROR      | 76  | 0.0066      | 0.00009  |       |                     |
| 1986 | PLOT       | 1   | 0.0043      | 0.0043   | 1.43  | 0.2546              |
|      | NEST(PLOT) | 12  | 0.0357      | 0.0030   | 16.31 | 0.0001              |
|      | ERROR      | 47  | 0.0086      | 0.0002   |       |                     |
| 1985 | PLOT       | 1   | 0.0008      | 0.0008   | 0.65  | 0.4242              |
|      | NEST(PLOT) | 42  | 0.0497      | 0.0012   | 8.97  | 0.0001              |
|      | ERROR      | 124 | 0.0163      | 0.0001   |       |                     |

<sup>a</sup> Plot effect approached significance.

# SMALL MAMMALS AND NESTING BIRDS 1990 ANNUAL REPORT

Table 41. Tree swallow growth constants derived from fitted growth curves. Data are from test (Pirilot Road) and control (Tachycineta Meadows) sites for 1985 through 1990. N = number of nestlings <sup>a</sup>.

| Variable | Year | TEST |           |      |       | CONTROL |           |      |       |
|----------|------|------|-----------|------|-------|---------|-----------|------|-------|
|          |      | N    | $\bar{X}$ | SD   | CV    | N       | $\bar{X}$ | SD   | CV    |
| Weight   | 1990 | 60   | 0.46      | 0.08 | 16.39 | 60      | 0.44      | 0.06 | 14.10 |
|          | 1989 | 21   | 0.44      | 0.06 | 13.20 | 30      | 0.47      | 0.06 | 13.05 |
|          | 1988 | 69   | 0.47      | 0.07 | 13.99 | 60      | 0.46      | 0.05 | 11.76 |
|          | 1987 | 42   | 0.46      | 0.06 | 12.30 | 61      | 0.49      | 0.07 | 14.31 |
|          | 1986 | 21   | 0.44      | 0.10 | 22.14 | 42      | 0.44      | 0.07 | 14.70 |
|          | 1985 | 102  | 0.48      | 0.08 | 15.93 | 61      | 0.44      | 0.06 | 14.54 |
| Tarsus   | 1990 | 64   | 0.36      | 0.07 | 19.79 | 70      | 0.37      | 0.07 | 17.83 |
|          | 1989 | 22   | 0.36      | 0.06 | 15.45 | 31      | 0.30      | 0.07 | 23.91 |
|          | 1988 | 75   | 0.46      | 0.14 | 30.73 | 69      | 0.47      | 0.10 | 20.48 |
|          | 1987 | 44   | 0.37      | 0.10 | 26.12 | 67      | 0.41      | 0.08 | 19.98 |
|          | 1986 | 21   | 0.36      | 0.06 | 17.12 | 42      | 0.36      | 0.09 | 23.98 |
|          | 1985 | 98   | 0.42      | 0.10 | 23.54 | 66      | 0.36      | 0.09 | 25.28 |
| Ulna     | 1990 | 64   | 0.33      | 0.05 | 15.26 | 69      | 0.34      | 0.05 | 16.29 |
|          | 1989 | 22   | 0.34      | 0.04 | 13.27 | 30      | 0.32      | 0.04 | 13.96 |
|          | 1988 | 74   | 0.37      | 0.06 | 15.94 | 68      | 0.37      | 0.04 | 10.58 |
|          | 1987 | 44   | 0.38      | 0.05 | 12.83 | 59      | 0.39      | 0.06 | 14.99 |
|          | 1986 | 20   | 0.36      | 0.04 | 10.88 | 41      | 0.36      | 0.06 | 15.87 |
|          | 1985 | 70   | 0.36      | 0.06 | 17.38 | 43      | 0.36      | 0.05 | 13.11 |
| Wing     | 1990 | 64   | 0.14      | 0.01 | 7.53  | 74      | 0.16      | 0.03 | 20.75 |
|          | 1989 | 22   | 0.13      | 0.01 | 4.85  | 30      | 0.13      | 0.01 | 7.37  |
|          | 1988 | 74   | 0.13      | 0.01 | 9.72  | 69      | 0.14      | 0.01 | 10.02 |
|          | 1987 | 44   | 0.13      | 0.01 | 10.04 | 56      | 0.13      | 0.01 | 9.40  |
|          | 1986 | 21   | 0.15      | 0.04 | 28.60 | 40      | 0.14      | 0.01 | 10.75 |
|          | 1985 | 102  | 0.15      | 0.02 | 14.03 | 66      | 0.15      | 0.02 | 12.58 |

<sup>a</sup>The numbers in this table are from completely reanalyzed data and may not agree with figures in earlier annual reports.

# SMALL MAMMALS AND NESTING BIRDS 1990 ANNUAL REPORT

Table 42. Tree swallow inflection points derived from fitted growth curves. Data are from test (Pirlot Road) and control (Tachycineta Meadows) sites for 1985 through 1990. N = number of nestlings.<sup>b</sup>

| Variable | Year | TEST |           |      |       | CONTROL |           |      |       |
|----------|------|------|-----------|------|-------|---------|-----------|------|-------|
|          |      | N    | $\bar{X}$ | SD   | CV    | N       | $\bar{X}$ | SD   | CV    |
| Weight   | 1990 | 60   | 5.94      | 1.01 | 17.02 | 60      | 6.20      | 1.03 | 16.53 |
|          | 1989 | 21   | 5.81      | 0.70 | 12.10 | 30      | 6.65      | 1.00 | 15.02 |
|          | 1988 | 69   | 5.47      | 0.74 | 13.57 | 60      | 5.49      | 0.74 | 13.44 |
|          | 1987 | 42   | 5.93      | 1.09 | 18.42 | 61      | 5.50      | 0.94 | 17.00 |
|          | 1986 | 21   | 6.53      | 1.16 | 17.72 | 42      | 6.51      | 0.89 | 13.66 |
|          | 1985 | 102  | 5.50      | 0.92 | 16.74 | 61      | 6.45      | 1.07 | 16.58 |
| Tarsus   | 1990 | 64   | 2.23      | 0.68 | 30.38 | 70      | 2.14      | 0.42 | 19.64 |
|          | 1989 | 22   | 2.55      | 0.51 | 19.95 | 31      | 3.66      | 0.89 | 24.37 |
|          | 1988 | 75   | 1.96      | 0.59 | 30.08 | 69      | 1.80      | 0.61 | 34.13 |
|          | 1987 | 44   | 2.16      | 1.20 | 55.53 | 67      | 2.33      | 0.74 | 32.00 |
|          | 1986 | 21   | 1.80      | 0.64 | 35.65 | 42      | 2.22      | 0.76 | 33.99 |
|          | 1985 | 98   | 2.05      | 0.56 | 27.51 | 66      | 2.55      | 0.87 | 34.29 |
| Ulna     | 1990 | 64   | 5.45      | 0.98 | 17.92 | 69      | 5.48      | 0.88 | 16.11 |
|          | 1989 | 22   | 5.51      | 0.75 | 13.70 | 30      | 6.49      | 1.04 | 15.98 |
|          | 1988 | 74   | 4.98      | 0.86 | 17.17 | 68      | 3.39      | 0.65 | 13.32 |
|          | 1987 | 44   | 5.39      | 1.08 | 20.03 | 59      | 4.95      | 0.88 | 17.79 |
|          | 1986 | 20   | 5.67      | 0.72 | 12.62 | 41      | 5.98      | 0.75 | 12.60 |
|          | 1985 | 70   | 5.63      | 1.08 | 19.10 | 43      | 6.15      | 0.87 | 14.22 |

Wing <sup>a</sup>

<sup>a</sup> Inflection point not applicable to curves for wing growth.

<sup>b</sup> The numbers in this table are from completely reanalyzed data and may not agree with figures in earlier annual reports.

# SMALL MAMMALS AND NESTING BIRDS 1990 ANNUAL REPORT

Table 43. The means of the slope of linear regression of growth measures on nestling age. Data are from test and control sites for 1985 through 1990.

| Variable | Year | TEST |           |       |      | CONTROL |           |       |      |
|----------|------|------|-----------|-------|------|---------|-----------|-------|------|
|          |      | N    | $\bar{X}$ | SD    | CV   | N       | $\bar{X}$ | SD    | CV   |
| Weight   | 1990 | 57   | 2.16      | 0.316 | 14.7 | 52      | 2.10      | 0.375 | 17.9 |
|          | 1989 | 23   | 1.99      | 0.299 | 15.0 | 31      | 2.27      | 0.545 | 23.1 |
|          | 1988 | 62   | 2.10      | 0.319 | 15.2 | 67      | 2.12      | 0.431 | 16.5 |
|          | 1987 | 43   | 2.11      | 0.255 | 12.1 | 61      | 2.10      | 0.324 | 15.4 |
|          | 1986 | 25   | 2.20      | 0.251 | 11.4 | 39      | 2.33      | 0.278 | 12.0 |
|          | 1985 | 96   | 2.16      | 0.307 | 14.2 | 65      | 2.23      | 0.321 | 14.4 |
| Tarsus   | 1990 | 39   | 0.74      | 0.167 | 22.4 | 35      | 0.65      | 0.149 | 22.8 |
|          | 1989 | 16   | 0.69      | 0.172 | 24.8 | 22      | 0.87      | 0.102 | 11.8 |
|          | 1988 | 14   | 0.60      | 0.184 | 30.6 | 26      | 0.54      | 0.161 | 29.6 |
|          | 1987 | 7    | 0.84      | 0.277 | 32.9 | 22      | 0.78      | 0.209 | 26.7 |
|          | 1986 | 18   | 0.72      | 0.122 | 16.9 | 18      | 0.63      | 0.126 | 19.9 |
|          | 1985 | 53   | 0.61      | 0.158 | 25.8 | 42      | 0.63      | 0.144 | 22.7 |
| Ulna     | 1990 | 56   | 2.15      | 0.251 | 11.7 | 55      | 2.29      | 0.386 | 16.9 |
|          | 1989 | 25   | 1.86      | 0.367 | 19.7 | 29      | 2.14      | 0.242 | 11.3 |
|          | 1988 | 63   | 2.08      | 0.210 | 10.1 | 64      | 2.05      | 0.228 | 11.1 |
|          | 1987 | 42   | 2.31      | 0.259 | 11.2 | 62      | 2.25      | 0.301 | 13.4 |
|          | 1986 | 24   | 2.34      | 0.181 | 7.7  | 33      | 2.47      | 0.165 | 6.7  |
|          | 1985 | 90   | 2.13      | 0.350 | 16.4 | 52      | 1.94      | 0.413 | 21.3 |

# SMALL MAMMALS AND NESTING BIRDS 1990 ANNUAL REPORT

Table 44. Means of maximum growth values attained by nestlings. Data are from test and control sites for 1985 through 1990.

| Variable | Year | TEST |           |       |     | CONTROL |           |       |      |
|----------|------|------|-----------|-------|-----|---------|-----------|-------|------|
|          |      | N    | $\bar{X}$ | SD    | CV  | N       | $\bar{X}$ | SD    | CV   |
| Weight   | 1990 | 54   | 22.59     | 1.882 | 8.3 | 34      | 22.52     | 1.935 | 8.6  |
|          | 1989 | 24   | 21.87     | 1.525 | 7.0 | 30      | 22.77     | 1.456 | 6.4  |
|          | 1988 | 73   | 21.93     | 1.833 | 8.4 | 58      | 22.65     | 1.945 | 8.6  |
|          | 1987 | 39   | 22.24     | 1.884 | 8.5 | 57      | 22.24     | 1.761 | 8.1  |
|          | 1986 | 17   | 23.60     | 1.051 | 4.5 | 41      | 22.88     | 1.563 | 6.8  |
|          | 1985 | 78   | 22.41     | 1.782 | 8.0 | 59      | 22.55     | 2.748 | 12.2 |
| Tarsus   | 1990 | 54   | 12.05     | 0.515 | 4.3 | 34      | 12.06     | 0.636 | 5.3  |
|          | 1989 | 24   | 12.08     | 0.921 | 7.6 | 30      | 12.31     | 0.286 | 2.3  |
|          | 1988 | 73   | 11.19     | 0.455 | 4.1 | 58      | 11.22     | 0.318 | 2.8  |
|          | 1987 | 39   | 11.74     | 0.659 | 5.6 | 59      | 11.81     | 0.546 | 4.6  |
|          | 1986 | 17   | 10.89     | 0.409 | 3.8 | 41      | 10.74     | 0.408 | 3.8  |
|          | 1985 | 77   | 11.13     | 0.488 | 4.4 | 59      | 10.99     | 0.673 | 6.1  |
| Ulna     | 1990 | 54   | 25.43     | 0.786 | 3.1 | 34      | 25.29     | 0.736 | 2.9  |
|          | 1989 | 24   | 24.79     | 0.710 | 2.9 | 30      | 25.18     | 0.678 | 2.7  |
|          | 1988 | 73   | 25.44     | 0.816 | 3.2 | 58      | 25.83     | 0.750 | 2.9  |
|          | 1987 | 39   | 26.40     | 0.897 | 3.4 | 57      | 25.95     | 1.061 | 4.1  |
|          | 1986 | 17   | 26.25     | 0.412 | 1.6 | 41      | 25.46     | 0.750 | 2.9  |
|          | 1985 | 78   | 24.48     | 2.367 | 9.7 | 59      | 24.86     | 2.407 | 9.7  |



# SMALL MAMMALS AND NESTING BIRDS 1990 ANNUAL REPORT

Table 45. The age of maximum growth values for growing nestling tree swallows. Data are from test and control sites for 1985 through 1990.

| Variable | Year | TEST |           |       |      | CONTROL |           |       |      |
|----------|------|------|-----------|-------|------|---------|-----------|-------|------|
|          |      | N    | $\bar{X}$ | SD    | CV   | N       | $\bar{X}$ | SD    | CV   |
| Weight   | 1990 | 54   | 13.06     | 1.327 | 10.2 | 34      | 13.74     | 1.366 | 9.9  |
|          | 1989 | 24   | 14.33     | 1.792 | 12.5 | 30      | 14.50     | 1.554 | 10.7 |
|          | 1988 | 73   | 14.14     | 1.836 | 13.0 | 58      | 13.45     | 1.921 | 14.3 |
|          | 1987 | 39   | 13.87     | 1.490 | 10.7 | 57      | 13.26     | 1.914 | 14.4 |
|          | 1986 | 17   | 14.35     | 1.618 | 11.3 | 41      | 14.29     | 1.569 | 11.0 |
|          | 1985 | 78   | 12.87     | 1.731 | 13.4 | 59      | 13.88     | 1.885 | 13.6 |
| Tarsus   | 1990 | 54   | 12.61     | 2.545 | 20.2 | 34      | 14.03     | 2.269 | 16.9 |
|          | 1989 | 24   | 14.50     | 1.700 | 11.7 | 30      | 14.83     | 1.768 | 11.9 |
|          | 1988 | 73   | 13.95     | 2.460 | 17.6 | 58      | 13.96     | 2.551 | 18.7 |
|          | 1987 | 39   | 13.62     | 2.642 | 19.1 | 57      | 13.86     | 2.642 | 19.1 |
|          | 1986 | 17   | 11.06     | 2.794 | 25.3 | 41      | 14.68     | 2.423 | 16.5 |
|          | 1985 | 78   | 13.46     | 2.208 | 16.4 | 59      | 13.51     | 2.322 | 17.2 |
| Ulna     | 1990 | 54   | 14.24     | 1.627 | 11.4 | 34      | 13.85     | 1.769 | 12.8 |
|          | 1989 | 24   | 15.17     | 1.381 | 9.1  | 30      | 15.97     | 1.655 | 10.4 |
|          | 1988 | 73   | 14.49     | 1.488 | 10.0 | 58      | 15.14     | 1.034 | 6.8  |
|          | 1987 | 39   | 14.74     | 1.681 | 11.4 | 57      | 14.46     | 1.833 | 12.7 |
|          | 1986 | 17   | 14.12     | 1.576 | 11.2 | 41      | 14.54     | 1.567 | 10.8 |
|          | 1985 | 78   | 13.69     | 1.995 | 14.6 | 59      | 14.56     | 1.794 | 12.4 |

# SMALL MAMMALS AND NESTING BIRDS 1990 ANNUAL REPORT

Table 46. Minimum detectable differences of means for growth constants and the minimum percent detectable change in the mean to reach 70% certainty (power) of test. <sup>a</sup> N = the number of nests per treatment for test or control. Detectable difference is in actual amount and percent of the grand mean.

| Variable | Year | N  | Actual<br>Detectable<br>Difference(%) | Actual<br>Power | % Detectable<br>Difference at<br>70% Power |
|----------|------|----|---------------------------------------|-----------------|--|
| Weight   | 1990 | 13 | 0.033(7.3)                            | <.30            | 0.125(27.8)                                |
|          | 1989 | 6  | 0.058(12.6)                           | <.30            | 0.155(33.7)                                |
|          | 1988 | 13 | 0.029(6.2)                            | <.30            | 0.105(22.3)                                |
|          | 1987 | 11 | 0.061(12.7)                           | <.30            | 0.118(24.6)                                |
|          | 1986 | 6  | 0.087(19.8)                           | <.30            | 0.232(52.7)                                |
|          | 1985 | 21 | 0.062(13.2)                           | <.30            | 0.100(21.3)                                |
| Tarsus   | 1990 | 13 | 0.035(9.5)                            | <.30            | 0.128(34.6)                                |
|          | 1989 | 6  | 0.125(39.1)                           | 0.40            | 0.185(57.8)                                |
|          | 1988 | 13 | 0.068(14.8)                           | <.30            | 0.195(42.4)                                |
|          | 1987 | 12 | 0.067(17.2)                           | <.30            | 0.150(38.5)                                |
|          | 1986 | 6  | 0.072(20.0)                           | <.30            | 0.192(53.3)                                |
|          | 1985 | 21 | 0.053(13.3)                           | <.30            | 0.112(28.0)                                |
| Ulna     | 1990 | 13 | 0.042(12.4)                           | <.30            | 0.109(32.1)                                |
|          | 1989 | 6  | 0.020(6.1)                            | <.30            | 0.126(38.2)                                |
|          | 1988 | 13 | 0.038(10.3)                           | <.30            | 0.098(26.5)                                |
|          | 1987 | 11 | 0.037(9.5)                            | <.30            | 0.095(24.4)                                |
|          | 1986 | 6  | 0.060(16.7)                           | <.30            | 0.160(44.4)                                |
|          | 1985 | 16 | 0.052(8.1)                            | <.30            | 0.086(23.9)                                |
| Wing     | 1990 | 13 | 0.031(20.7)                           | .30             | 0.053(35.3)                                |
|          | 1989 | 6  | 0.026(20.0)                           | <.30            | 0.068(52.3)                                |
|          | 1988 | 13 | 0.008(6.2)                            | <.30            | 0.023(17.7)                                |
|          | 1987 | 11 | 0.004(3.1)                            | <.30            | 0.022(16.9)                                |
|          | 1986 | 6  | 0.021(15.0)                           | <.30            | 0.085(60.7)                                |
|          | 1985 | 21 | 0.006(4.0)                            | <.30            | 0.027(18.0)                                |

<sup>a</sup> The data in this table have been reanalyzed using N = number of nests per treatment and do not agree with figures in earlier annual reports.

# SMALL MAMMALS AND NESTING BIRDS 1990 ANNUAL REPORT

Table 47. Minimum detectable differences in mean inflection points and the minimum percent detectable change in the mean to reach 70% certainty (power) of test. <sup>a</sup> N = the number of nests per treatment for test or control.

| Variable | Year | N  | Actual Detectable Difference(%) | Actual Power | % Detectable Difference at 70% Power |
|----------|------|----|---------------------------------|--------------|--------------------------------------|
| Weight   | 1990 | 13 | 0.656(10.8)                     | <.30         | 1.85(30.1)                           |
|          | 1989 | 6  | 1.520(24.1)                     | .40          | 2.20(34.9)                           |
|          | 1988 | 13 | 0.477(8.7)                      | <.30         | 1.23(22.4)                           |
|          | 1987 | 11 | 0.387(6.8)                      | <.30         | 1.95(34.3)                           |
|          | 1986 | 6  | 1.090(16.7)                     | <.30         | 2.90(44.5)                           |
|          | 1985 | 21 | 1.162(19.8)                     | .59          | 1.28(21.8)                           |
| Tarsus   | 1990 | 13 | 0.234(10.7)                     | <.30         | 0.95(43.6)                           |
|          | 1989 | 6  | 1.656(51.8)                     | .55          | 1.99(62.2)                           |
|          | 1988 | 13 | 0.218(11.6)                     | <.30         | 1.03(54.8)                           |
|          | 1987 | 12 | 0.619(27.4)                     | <.30         | 1.82(80.5)                           |
|          | 1986 | 6  | 0.606(31.7)                     | <.30         | 1.98(95.2)                           |
|          | 1985 | 21 | 0.505(22.4)                     | .30          | 0.86(38.2)                           |
| Ulna     | 1990 | 13 | 0.669(12.2)                     | <.30         | 1.75(32.0)                           |
|          | 1989 | 6  | 1.750(28.9)                     | .45          | 2.41(39.6)                           |
|          | 1988 | 13 | 0.524(10.6)                     | <.30         | 1.45(29.4)                           |
|          | 1987 | 11 | 0.447(8.7)                      | <.30         | 1.95(37.9)                           |
|          | 1986 | 6  | 0.569(9.7)                      | <.30         | 2.09(35.5)                           |
|          | 1985 | 16 | 0.209(3.6)                      | <.30         | 1.54(26.4)                           |

Wing <sup>a</sup>

<sup>a</sup> Inflection point not applicable to curves for wing growth.

<sup>b</sup> The data in this table have been reanalyzed using N = number of nests per treatment and do not agree with figures in earlier annual reports.

# SMALL MAMMALS AND NESTING BIRDS 1990 ANNUAL REPORT

Table 48. Minimum detectable differences of means for linear growth rate and the minimum percent detectable change (n parentheses) in the mean to reach a 70% certainty (i.e. power) of test. Data are grouped by year with number of nests used for power calculation as 'N'.

| Variable | Year | N  | Actual<br>Detectable<br>Difference (%) | Actual<br>Power | Detectable<br>Difference at 70%<br>Power (% change) |
|----------|------|----|--|-----------------|---|
| Weight   | 1990 | 12 | 0.182 ( 8.5)                           | < 0.30          | 0.57 (26.7)   |
|          | 1989 | 8  | 0.306 (14.2)                           | < 0.30          | 1.10 (51.1)   |
|          | 1988 | 14 | 0.216 (10.2)                           | < 0.30          | 0.70 (33.2)   |
|          | 1987 | 11 | 0.184 ( 8.7)                           | < 0.30          | 0.49 (23.3)   |
|          | 1986 | 7  | 0.187 ( 8.2)                           | < 0.30          | 0.60 (26.3)   |
|          | 1985 | 19 | 0.169 ( 7.7)                           | < 0.30          | 0.44 (20.1)   |
| Tarsus   | 1990 | 12 | 0.088 (12.6)                           | < 0.30          | 0.23 (33.0)   |
|          | 1989 | 6  | 0.197 (24.8)                           | < 0.35          | 0.33 (41.6)   |
|          | 1988 | 7  | 0.088 (15.7)                           | < 0.30          | 0.34 (60.6)   |
|          | 1987 | 6  | 0.160 (20.1)                           | < 0.30          | 0.48 (60.4)   |
|          | 1986 | 5  | 0.028 ( 4.2)                           | < 0.30          | 0.33 (48.9)   |
|          | 1985 | 17 | 0.073 (11.8)                           | < 0.30          | 0.18 (29.1)   |
| Ulna     | 1990 | 14 | 0.184 ( 8.3)                           | < 0.30          | 0.58 (26.1)   |
|          | 1989 | 9  | 0.433 (20.7)                           | 0.53            | 0.60 (28.7)   |
|          | 1988 | 17 | 0.068 ( 3.3)                           | < 0.30          | 0.28 (13.6)   |
|          | 1987 | 12 | 0.077 ( 3.4)                           | < 0.30          | 0.48 (21.1)   |
|          | 1986 | 5  | 0.238 ( 9.9)                           | < 0.30          | 0.47 (19.5)   |
|          | 1985 | 18 | 0.137 ( 6.6)                           | < 0.30          | 0.55 (26.7)   |

# SMALL MAMMALS AND NESTING BIRDS 1990 ANNUAL REPORT

Table 49. Minimum detectable differences of means for maximum attained values and the minimum percent detectable change (n parentheses) in the mean to reach a 70% certainty (i.e. power) of test. Data are grouped by year with number of nests used for power calculation as 'N'.

| Variable | Year | N  | Actual<br>Detectable<br>Difference (%) | Actual<br>Power | Detectable<br>Difference at 70%<br>Power (% change) |
|----------|------|----|--|-----------------|---|
| Weight   | 1990 | 9  | 1.453 ( 6.4)                           | < 0.30          | 4.40 (19.5)   |
|          | 1989 | 7  | 0.913 ( 4.1)                           | < 0.30          | 3.00 (13.4)   |
|          | 1988 | 13 | 1.046 ( 4.7)                           | < 0.30          | 3.40 (15.3)   |
|          | 1987 | 11 | 0.732 ( 3.3)                           | < 0.30          | 3.30 (14.8)   |
|          | 1986 | 6  | 0.936 ( 4.1)                           | < 0.30          | 3.40 (14.7)   |
|          | 1985 | 18 | 1.045 ( 4.6)                           | < 0.30          | 1.88 ( 8.4)   |
| Tarsus   | 1990 | 9  | 0.339 ( 2.8)                           | < 0.30          | 1.04 ( 8.6)   |
|          | 1989 | 7  | 0.262 ( 2.1)                           | < 0.30          | 0.78 ( 6.4)   |
|          | 1988 | 3  | 0.250 ( 2.2)                           | < 0.30          | 0.69 ( 6.2)   |
|          | 1987 | 11 | 0.235 ( 2.0)                           | < 0.30          | 0.62 ( 5.3)   |
|          | 1986 | 6  | 0.100 ( 0.9)                           | < 0.30          | 1.10 (10.2)   |
|          | 1985 | 18 | 0.129 ( 1.2)                           | < 0.30          | 0.67 ( 6.1)   |
| Ulna     | 1990 | 9  | 0.366 ( 1.4)                           | < 0.30          | 1.18 ( 4.7)   |
|          | 1989 | 7  | 0.365 ( 1.4)                           | < 0.30          | 1.65 ( 6.6)   |
|          | 1988 | 13 | 0.591 ( 2.3)                           | < 0.30          | 1.31 ( 5.1)   |
|          | 1987 | 11 | 1.144 ( 4.4)                           | 0.35            | 1.58 ( 1.7)   |
|          | 1986 | 6  | 1.593 ( 6.2)                           | 0.63            | 1.72 ( 6.7)   |
|          | 1985 | 18 | 0.889 ( 3.6)                           | < 0.30          | 3.21 (13.0)   |

# SMALL MAMMALS AND NESTING BIRDS 1990 ANNUAL REPORT

Table 50. Minimum detectable differences of means for age at attaining the maximum value for variables and the minimum percent detectable change (in parentheses) in the mean to reach a 70% certainty (i.e. power) of test. Data are grouped by year with number of nests used for power calculation as 'N'.

| Variable | Year | N  | Actual<br>Detectable<br>Difference (%) | Actual<br>Power | Detectable<br>Difference at 70%<br>Power (% change) |
|----------|------|----|--|-----------------|---|
| Weight   | 1990 | 9  | 0.493 ( 3.7)                           | < 0.30          | 2.51 (18.8)   |
|          | 1989 | 7  | 0.680 ( 4.7)                           | < 0.30          | 3.69 (25.6)   |
|          | 1988 | 13 | 0.416 ( 3.0)                           | < 0.30          | 3.40 (24.6)   |
|          | 1987 | 11 | 0.878 ( 6.6)                           | < 0.30          | 2.90 (21.5)   |
|          | 1986 | 6  | 1.422 ( 9.9)                           | < 0.30          | 4.25 (29.7)   |
|          | 1985 | 18 | 1.907 (14.3)                           | 0.93            | 1.33 (10.0)   |
| Tarsus   | 1990 | 9  | 2.035 (15.5)                           | < 0.30          | 3.85 (29.3)   |
|          | 1989 | 7  | 0.942 ( 6.4)                           | < 0.30          | 4.41 (30.0)   |
|          | 1988 | 13 | 0.962 ( 6.9)                           | < 0.30          | 2.75 (19.7)   |
|          | 1987 | 11 | 1.542 (11.2)                           | < 0.30          | 4.35 (31.6)   |
|          | 1986 | 6  | 5.617 (41.2)                           | 0.74            | 5.35 (39.3)   |
|          | 1985 | 18 | 0.962 ( 7.1)                           | < 0.30          | 2.55 (18.9)   |
| Ulna     | 1990 | 15 | 1.660 (11.5)                           | < 0.30          | 4.45 (31.6)   |
|          | 1989 | 7  | 0.657 ( 4.2)                           | < 0.30          | 3.90 (24.7)   |
|          | 1988 | 13 | 0.576 ( 3.9)                           | < 0.30          | 1.85 (12.5)   |
|          | 1987 | 11 | 0.910 ( 6.2)                           | < 0.30          | 3.05 (20.9)   |
|          | 1986 | 6  | 0.873 ( 5.9)                           | < 0.30          | 3.90 (26.2)   |
|          | 1985 | 19 | 1.989 (14.0)                           | 0.65            | 2.05 (14.5)   |

# SMALL MAMMALS AND NESTING BIRDS 1990 ANNUAL REPORT

Table 51. Statistics for growth rate of body mass for young deermice compared by year and plot. Growth rate is the slope of a linear model.

| Year | Control |           |       |      | Test |           |       |      |
|------|---------|-----------|-------|------|------|-----------|-------|------|
|      | N       | $\bar{X}$ | Std D | CV%  | N    | $\bar{X}$ | Std D | CV%  |
| 1990 | 58      | 0.34      | 0.046 | 13.6 | 27   | 0.30      | 0.048 | 15.7 |
| 1989 | 15      | 0.30      | 0.045 | 15.1 | 14   | 0.38      | 0.050 | 13.1 |
| 1988 | 32      | 0.33      | 0.062 | 18.6 | 35   | 0.37      | 0.064 | 17.1 |
| 1987 | 47      | 0.38      | 0.063 | 16.4 | 42   | 0.31      | 0.077 | 25.2 |
| 1986 | 42      | 0.25      | 0.091 | 36.2 | 50   | 0.28      | 0.085 | 29.9 |

Table 52. Nested ANOVA of deermice growth rates on test (Pirilot Road) and control (Michigamme) sites for years 1986 through 1990. Tested are the effects of plots, PLOT, and litters within a plot, MOTHER(PLOT).

| Year | Source       | DF | Type III SS | MS     | F-Value | P > F              |
|------|--------------|----|-------------|--------|---------|--------------------|
| 1990 | PLOT         | 1  | 0.020       | 0.020  | 1.76    | 0.206              |
|      | MOTHER(PLOT) | 14 | 0.158       | 0.011  | 36.20   | 0.0001             |
|      | ERROR        | 69 | 0.022       | 0.0003 |         |                    |
| 1989 | PLOT         | 1  | 0.058       | 0.058  | 4.60    | 0.097 <sup>a</sup> |
|      | MOTHER(PLOT) | 4  | 0.051       | 0.013  | 29.75   | 0.001              |
|      | ERROR        | 23 | 0.010       | 0.0004 |         |                    |
| 1988 | PLOT         | 1  | 0.024       | 0.024  | 1.18    | 0.300              |
|      | MOTHER(PLOT) | 11 | 0.221       | 0.020  | 28.81   | 0.0001             |
|      | ERROR        | 54 | 0.038       | 0.0007 |         |                    |
| 1987 | PLOT         | 1  | 0.0008      | 0.0008 | 0.03    | 0.855              |
|      | MOTHER(PLOT) | 14 | 0.338       | 0.0241 | 31.39   | 0.0001             |
|      | ERROR        | 71 | 0.055       | 0.0008 |         |                    |
| 1986 | PLOT         | 1  | 0.054       | 0.054  | 3.21    | 0.095 <sup>a</sup> |
|      | MOTHER(PLOT) | 14 | 0.234       | 0.017  | 14.25   | 0.0001             |
|      | ERROR        | 70 | 0.082       | 0.001  |         |                    |

<sup>a</sup> Plot effect approached significance.

# **SMALL MAMMALS AND NESTING BIRDS 1990 ANNUAL REPORT**

Table 53. Minimum detectable differences and power for deermice growth constants for years 1986 - 1990.

| Year | N | Actual<br>Detectable<br>Difference(%) | Actual<br>Power | Detectable<br>Difference at 70%<br>Power (% change) |
|------|---|---------------------------------------|-----------------|---|
| 1990 | 7 | 0.051(15.6)                           | <.30            | 0.15(45.8)  |
| 1989 | 2 | 0.212(62.4)                           | .33             | 0.34(100.0)   |
| 1988 | 5 | 0.040(11.4)                           | <.30            | 0.24(68.6)  |
| 1987 | 7 | 0.082(23.6)                           | <.30            | 0.22(63.4)  |
| 1986 | 7 | 0.103(38.1)                           | .30             | 0.19(68.5)  |

Table 54. Relevant statistics for age of eye-opening and incisor eruption for deermice reared in enclosures from 1985 through 1990.

| Year | Plot    | <u>Eye Opening</u> |           |      | <u>Incisor Eruption</u> |           |      |
|------|---------|--------------------|-----------|------|-------------------------|-----------|------|
|      |         | n                  | $\bar{X}$ | SD   | n                       | $\bar{X}$ | SD   |
| 1990 | Test    | 27                 | 14.9      | 1.68 | 27                      | 5.9       | 1.19 |
|      | Control | 58                 | 17.3      | 1.52 | 58                      | 5.9       | 1.18 |
| 1989 | Test    | 14                 | 15.3      | 1.14 | 14                      | 5.0       | 0.88 |
|      | Control | 15                 | 15.7      | 3.01 | 15                      | 6.0       | 1.51 |
| 1988 | Test    | 35                 | 14.7      | 1.44 | 35                      | 4.4       | 0.91 |
|      | Control | 32                 | 16.3      | 1.37 | 32                      | 5.5       | 0.80 |
| 1987 | Test    | 44                 | 15.7      | 1.87 | 44                      | 6.1       | 1.55 |
|      | Control | 43                 | 16.0      | 1.10 | 43                      | 6.4       | 1.66 |
| 1986 | Test    | 28                 | 14.1      | 2.01 | 28                      | 5.6       | 1.29 |
|      | Control | 48                 | 15.0      | 1.08 | 48                      | 6.1       | 1.49 |



# SMALL MAMMALS AND NESTING BIRDS 1990 ANNUAL REPORT

Table 55. Nested ANOVA of deermice age of eye opening on test (Pirlot Road) and control (Michigamme) sites for years 1985 through 1990. Tested are the effects of plots, PLOT, and litters within a plot, MOTHER(PLOT).

| Year | Source       | DF | Type III SS | MS      | F-Value | F > F              |
|------|--------------|----|-------------|---------|---------|--------------------|
| 1990 | PLOT         | 1  | 115.205     | 115.205 | 8.65    | 0.011 <sup>a</sup> |
|      | MOTHER(PLOT) | 14 | 186.355     | 13.311  | 47.18   | 0.0001             |
|      | ERROR        | 69 | 19.467      | 0.282   |         |                    |
| 1989 | PLOT         | 1  | 4.298       | 4.298   | 0.13    | 0.733              |
|      | MOTHER(PLOT) | 4  | 128.457     | 32.114  | 48.17   | 0.0001             |
|      | ERROR        | 23 | 15.333      | 0.667   |         |                    |
| 1988 | PLOT         | 1  | 37.020      | 37.020  | 3.92    | 0.073 <sup>b</sup> |
|      | MOTHER(PLOT) | 11 | 103.954     | 9.450   | 20.25   | 0.0001             |
|      | ERROR        | 54 | 25.200      | 0.467   |         |                    |
| 1987 | PLOT         | 1  | 3.458       | 3.458   | 0.28    | 0.603              |
|      | MOTHER(PLOT) | 14 | 170.739     | 12.196  | 28.74   | 0.0001             |
|      | ERROR        | 71 | 30.124      | 0.424   |         |                    |
| 1986 | PLOT         | 1  | 9.630       | 9.630   | 0.76    | 0.400              |
|      | MOTHER(PLOT) | 12 | 151.674     | 12.640  | 61.54   | 0.0001             |
|      | ERROR        | 62 | 12.733      | 0.205   |         |                    |

<sup>a</sup> Plot effect reached significance.

<sup>b</sup> Plot effect approached significance.

# SMALL MAMMALS AND NESTING BIRDS 1990 ANNUAL REPORT

Table 56. Nested ANOVA of deermice incisor eruption on test (Pirlot Road) and control (Michigamme) sites for years 1986 through 1990. Tested are the effects of plots, PLOT, and litters within a plot, MOTHER(PLOT).

| Year | Source       | DF | Type III SS        | MS     | F-Value  | P > F              |
|------|--------------|----|--------------------|--------|----------|--------------------|
| 1990 | PLOT         | 1  | 0.014              | 0.014  | 0.00     | 0.954              |
|      | MOTHER(PLOT) | 14 | 57.684             | 4.120  | 4.87     | 0.0001             |
|      | ERROR        | 69 | 58.362             | 0.846  |          |                    |
| 1989 | PLOT         | 1  | 5.337              | 5.337  | 0.55     | 0.499              |
|      | MOTHER(PLOT) | 4  | 38.800             | 9.700  | 69.72    | 0.0001             |
|      | ERROR        | 23 | 3.200              | 0.139  |          |                    |
| 1988 | PLOT         | 1  | 19.008             | 19.008 | 4.32     | 0.062 <sup>a</sup> |
|      | MOTHER(PLOT) | 11 | 48.369             | 4.397  | 99999.99 | 0.000              |
|      | ERROR        | 54 | 0.000 <sup>*</sup> | 0.000  |          |                    |
| 1987 | PLOT         | 1  | 5.650              | 5.650  | 0.40     | 0.535              |
|      | MOTHER(PLOT) | 14 | 195.684            | 13.977 | 42.43    | 0.0001             |
|      | ERROR        | 71 | 23.391             | 0.329  |          |                    |
| 1986 | PLOT         | 1  | 1.289              | 1.289  | 0.14     | 0.713              |
|      | MOTHER(PLOT) | 12 | 109.279            | 9.107  | 13.98    | 0.0001             |
|      | ERROR        | 62 | 40.390             | 0.651  |          |                    |

<sup>a</sup> Plot effect approached significance.

<sup>\*</sup> - very small number

# SMALL MAMMALS AND NESTING BIRDS 1990 ANNUAL REPORT

Table 57. Minimum detectable differences and power for deermice maturation events for years 1986 through 1990.

| Year                      | N    | Actual Detectable Difference(%) |            | Actual Power | Detectable Difference at 70% Power (% change) |
|---------------------------|------|---------------------------------|------------|--------------|---|
| Eye opening days (%)      | 1990 | 7                               | 5.4 (32.7) | .74          | 5.2(31.5)                                     |
|                           | 1989 | 2                               | 5.27(34.0) | <.30         | 16.8(108.4)                                   |
|                           | 1988 | 5                               | 3.32(21.4) | .33          | 5.4(34.5)                                     |
|                           | 1987 | 7                               | 1.58(10.0) | <.30         | 5.0(31.6)                                     |
|                           | 1986 | 6                               | 1.00( 6.8) | <.30         | 5.6(38.1)                                     |
| Incisor eruption days (%) | 1990 | 7                               | 1.08(18.3) | <.30         | 2.9(49.2)                                     |
|                           | 1989 | 2                               | 2.09(38.0) | <.30         | 9.2(167.3)                                    |
|                           | 1988 | 5                               | 2.42(49.1) | .35          | 3.5(71.0)                                     |
|                           | 1987 | 7                               | 1.54(24.9) | <.30         | 5.3(85.5)                                     |
|                           | 1986 | 6                               | 1.61(27.4) | <.30         | 4.7(79.7)                                     |

Table 58. Numbers of birds used in the tree swallow homing study and likelihood to return following displacement, 1986-1990. Returns are those birds which returned to the plot in less than 300 minutes. Likelihood to return was assessed using G-tests (Sokal and Rohlf 1981).

| Year | Treatment | Return | Not Return |             |           |
|------|-----------|--------|------------|-------------|-----------|
| 1990 | Test      | 41     | 1          | G = 8.527   | P < 0.005 |
|      | Control   | 30     | 9          |             |           |
| 1989 | Test      | 14     | 0          | Not tested- | see text  |
|      | Control   | 15     | 1          |             |           |
| 1988 | Test      | 37     | 4          | G = 0.256   | P > 0.5   |
|      | Control   | 39     | 6          |             |           |
| 1987 | Test      | 36     | 1          | G = 13.675  | P < 0.001 |
|      | Control   | 25     | 13         |             |           |
| 1986 | Test      | 26     | 3          | G = 1.577   | P > 0.1   |
|      | Control   | 24     | 7          |             |           |

# SMALL MAMMALS AND NESTING BIRDS 1990 ANNUAL REPORT

Table 59. Mean return times of tree swallows in minutes for 1986-1990 field seasons. Data for the two test sites were pooled after determining that there were no significant differences between them.

| Year | Treatment | $\bar{X}$ | SD   | n  | Difference (min) |
|------|-----------|-----------|------|----|------------------|
| 1990 | Test      | 148.3     | 54.5 | 41 | 23.9             |
|      | Control   | 172.2     | 53.3 | 30 |                  |
| 1989 | Test      | 118.1     | 47.7 | 14 | 50.0             |
|      | Control   | 168.1     | 53.4 | 15 |                  |
| 1988 | Test      | 136.8     | 39.5 | 37 | 53.0             |
|      | Control   | 189.8     | 54.4 | 39 |                  |
| 1987 | Test      | 155.1     | 46.2 | 36 | 47.3             |
|      | Control   | 202.4     | 55.6 | 25 |                  |
| 1986 | Test      | 149.8     | 52.6 | 26 | 27.1             |
|      | Control   | 176.9     | 67.0 | 22 |                  |

Table 60. Analysis of variance comparing tree swallow return times in minutes for 1986-1990 field seasons. Variables considered are PLOT(test and control), YEAR and PLOT/YEAR interaction.

| Source    | DF  | Type III SS | MS         | F     | P > F  |
|-----------|-----|-------------|------------|-------|--------|
| PLOT      | 1   | 101380.107  | 101380.107 | 37.11 | 0.0001 |
| YEAR      | 4   | 26472.579   | 6618.145   | 2.42  | 0.0486 |
| PLOT*YEAR | 4   | 11256.835   | 2814.209   | 1.03  | 0.3920 |
| ERROR     | 275 | 751283.780  | 2731.941   |       |        |

# SMALL MAMMALS AND NESTING BIRDS 1990 ANNUAL REPORT

Table 61. Data on tree swallow likelihood to return pooled over all years (1986-1990) for test and control plots.

| Plot    | Return | Not<br>Return |
|---------|--------|---------------|
| Test    | 154    | 9             |
| Control | 133    | 36            |

G = 15.566 P < 0.001

Table 62. Detectable differences and power for tree swallow homing: return time for years 1986 - 1990. N = number of adults per treatment for test or control. Differences presented in minutes with % following.

| Variable                  | N   | Actual<br>Detectable<br>Difference(%) | Actual<br>Power | Detectable<br>Difference at 70%<br>Power (% change) |
|---------------------------|-----|---------------------------------------|-----------------|---|
| Return time<br>minutes(%) | 137 | 37.9 (23.9)                           | 1.0             | 16 (10.1)   |

# SMALL MAMMALS AND NESTING BIRDS 1990 ANNUAL REPORT

Table 63. Results of the small mammal homing studies at Pirlot Road test site and Michigamme control during the antenna operational years of 1989 and 1990.

| Species                       | Year                       | Plot    | Return | Not<br>Return | %    |         |
|-------------------------------|----------------------------|---------|--------|---------------|------|---------|
| Chipmunks                     | 1990                       | Test    | 11     | 12            | 47.8 | G=2.477 |
|                               |                            | Control | 15     | 6             | 71.4 | P>0.1   |
|                               | 1989                       | Test    | 15     | 8             | 65.2 | G=0.306 |
|                               |                            | Control | 9      | 7             | 56.3 | P>0.5   |
|                               | Overall G=2.844 df=3 P>0.1 |         |        |               |      |         |
|                               | Deermice                   | 1990    | Test   | 20            | 23   | 46.5    |
| Control                       |                            |         | 29     | 6             | 82.9 | P<0.001 |
| 1989                          |                            | Test    | 13     | 8             | 61.9 | G=4.83  |
|                               |                            | Control | 3      | 10            | 23.1 | P<0.05  |
| Overall G=18.401 df=3 P<0.001 |                            |         |        |               |      |         |

Table 64. Frequency of tree swallow abnormalities, 1990. First number is the number of embryos displaying abnormality. Second number (in parentheses) is number of nests involved.

|                        | No<br>Development | Spine<br>Abnormal   | Allantois<br>Reversed | Other |
|------------------------|-------------------|---------------------|-----------------------|-------|
| Test                   | 2 (2)             | 10 (7)              | 1 (1)                 | 2 (2) |
| Control                | 0                 | 11 <sup>a</sup> (6) | 4 (4)                 | 3 (3) |
| Percentage<br>Abnormal | 1.4%              | 14.6%               | 3.5%                  | 3.5%  |

<sup>a</sup> Three embryos included under spinal abnormality showed reversed allantoic development as well.

# SMALL MAMMALS AND NESTING BIRDS 1990 ANNUAL REPORT

Table 65. Chi-square analysis of developmental abnormalities found in early tree swallow embryos collected from test and control sites. Analysis excludes embryos with dorsally directed allantois, since these are probably a variation of normal development.

|          | Test | Control | Total |
|----------|------|---------|-------|
| Normal   | 53   | 63      | 116   |
| Abnormal | 14   | 14      | 28    |
| Total    | 67   | 77      | 144   |

$$X^2 = 0.17$$

$$\text{Contingency coefficient} = 0.03$$

Table 66. Chi-square analysis of developmental abnormalities found in early tree swallow embryos collected from test and control sites. Analysis includes embryos with dorsally directed allantois which were excluded from Table 65.

|          | Test | Control | Total |
|----------|------|---------|-------|
| Normal   | 52   | 59      | 111   |
| Abnormal | 15   | 18      | 33    |
| Total    | 67   | 77      | 144   |

$$X^2 = 0.02$$

$$\text{Contingency coefficient} = 0.01$$

# **SMALL MAMMALS AND NESTING BIRDS 1990 ANNUAL REPORT**

Table 67. Calculated volumes of tree swallow eggs collected from test and control plots.

| Test     |                  |      | Control  |                  |      |
|----------|------------------|------|----------|------------------|------|
| Nest No. | Mean Volume (cc) | S.D. | Nest No. | Mean Volume (cc) | S.D. |
| 1        | 1.58             | 0.07 | 2        | 1.66             | 0.04 |
| 4        | 1.55             | 0.08 | 3        | 1.53             | 0.06 |
| 6        | 1.63             | 0.09 | 5        | 1.65             | 0.10 |
| 16       | 1.44             | 0.07 | 7        | 1.65             | 0.14 |
| 18       | 1.82             | 0.10 | 8        | 1.71             | 0.06 |
| 19       | 1.72             | 0.03 | 9        | 1.61             | 0.06 |
| 23       | 1.64             | 0.08 | 10       | 1.43             | 0.06 |
| 24       | 1.76             | 0.07 | 11       | 1.61             | 0.04 |
| 25       | 1.70             | 0.15 | 12       | 1.63             | 0.07 |
| 26       | 1.62             | 0.09 | 14       | 1.60             | 0.09 |
| 27       | 1.65             | 0.02 | 15       | 1.51             | 0.09 |
| 28       | 1.69             | 0.05 | 20       | 1.64             | 0.12 |
| 29       | 1.49             | 0.17 | 21       | 1.68             | 0.07 |
| 30       | 1.63             | 0.04 |          |                  |      |

Table 68. Egg weights and volumes - basic statistics.

|             | Weight  |       | Volume  |       |
|-------------|---------|-------|---------|-------|
|             | Control | Test  | Control | Test  |
| No. of eggs | 76      | 72    | 67      | 68    |
| Mean        | 1.727   | 1.750 | 1.603   | 1.634 |
| Minimum     | 1.450   | 1.270 | 1.340   | 1.350 |
| Maximum     | 2.170   | 2.080 | 1.840   | 1.910 |
| Range       | 0.720   | 0.810 | 0.500   | 0.560 |
| Variance    | 0.018   | 0.021 | 0.011   | 0.015 |
| Std. Dev.   | 0.136   | 0.146 | 0.107   | 0.124 |
| Std. Error  | 0.016   | 0.017 | 0.013   | 0.015 |
| C.V.        | 0.078   | 0.083 | 0.067   | 0.076 |



# SMALL MAMMALS AND NESTING BIRDS 1990 ANNUAL REPORT

Table 69. Nested Analysis of Variance of egg weights for test and control plots and nests within plots. The error term for PLOT is the mean square error for NEST(PLOT).

| Source     | SS      | DF  | MS      | F     | P      |
|------------|---------|-----|---------|-------|--------|
| PLOT       | 0.005   | 1   | 0.00491 | 0.654 | 0.420  |
| NEST(PLOT) | 2.007   | 28  | 0.07168 | 9.558 | 0.0001 |
| ERROR      | 0.88487 | 118 | 0.00750 |       |        |

Table 70. Nested Analysis of Variance of egg volume for test and control plots and eggs within nests. The error term for PLOT is the mean square error for NEST(PLOT).

| Source     | SS      | DF  | MS      | F     | P     |
|------------|---------|-----|---------|-------|-------|
| PLOT       | 0.01153 | 1   | 0.01153 | 1.675 | 0.198 |
| NEST(PLOT) | 1.04516 | 26  | 0.04020 | 5.839 | 0.001 |
| ERROR      | 0.73662 | 107 | 0.00688 |       |       |

# SMALL MAMMALS AND NESTING BIRDS 1990 ANNUAL REPORT

Table 71. Summary of peak metabolic rates measured on deermice and chickadees in the week following capture in 1990. All measured peaks, regardless of their quality rating, are reported.

| Species and Plot | Number of Measures | Peak Metabolic Rate<br>[ml O <sub>2</sub> /(g X hr)] |      | Mean Body Weight |
|------------------|--------------------|--|------|------------------|
|                  |                    | Mean   | S.D. | (g)              |
|                  |                    |  |      |                  |
| Deermice         |                    |  |      |                  |
| MGE (Control)    | 12                 | 18.1   | 1.6  | 21.2             |
| PRT (Test)       | 10                 | 19.3   | 2.2  | 18.1             |
| Chickadees       |                    |  |      |                  |
| MGE              | 13                 | 24.4   | 1.8  | 10.9             |
| PRT              | 11                 | 24.2   | 1.9  | 11.0             |

# SMALL MAMMALS AND NESTING BIRDS 1990 ANNUAL REPORT

Table 72. Summary of major findings by task for 1985-1990.

| Task   | Results                        | Year           |
|--|--------------------------------|----------------|
| <b><u>SMALL MAMMAL COMMUNITIES<sup>a</sup></u></b>                         |                                |                |
| Species richness. . . . .  | Test greater than Control. . . | 88,87          |
| Species composition . . . .  | No Plot effect . . . . .       | 88,87,86,85    |
| Species diversity . . . . .  | Test greater than Control. . . | 88             |
|  | Test less than Control . . .   | 87             |
|  | No Plot effect . . . . .       | 86,85          |
| Evenness. . . . .  | Test greater than Control. . . | 88             |
|  | Test less than control . . .   | 87             |
|  | No Plot effect . . . . .       | 86,85          |
| TPN - chipmunk . . . . .   | Test less than Control . . .   | 88,87,86,85    |
| TPN - deer mouse. . . . .  | Test greater than Control. . . | 88,87          |
|  | No Plot effect . . . . .       | 86,85          |
| <b><u>TREE SWALLOW - FECUNDITY, GROWTH AND MATURATION STUDIES</u></b>      |                                |                |
| Mean clutch size. . . . .  | No Plot or Year effect . . .   | all years      |
| Distrib. of clutch size. . .   | No Plot or Year effect . . .   | all years      |
| Likelihood to hatch . . . .  | No Plot or Year effect . . .   | all years      |
| Hatch rate. . . . .  | Year effect, no Plot effect.   | all years      |
| Likelihood to fledge. . . .  | Year effect, no Plot effect.   | all years      |
| Number fledged. . . . .  | Year effect, no Plot effect.   | all years      |
| <b><u>Landmark growth events</u></b>                                       |                                |                |
| Eye opening . . . . .  | Nest effect, no Plot effect.   | all years      |
| Feather eruption. . . . .  | Nest effect, no Plot effect.   | all years      |
| <b><u>Mortality<sup>a</sup> (3 test, 2 control plots. Data pooled)</u></b> |                                |                |
| Egg . . . . .  | Test greater than Control. . . | 87,90          |
|  | Test less than Control . . .   | 88,86          |
|  | No Plot effect . . . . .       | 89,85          |
| Nestling. . . . .  | Test greater than Control. . . | 86,90          |
|  | Test less than Control . . .   | 85,88          |
|  | No Plot effect . . . . .       | 89,87          |
| Overall Nest. . . . .  | Test greater than Control. . . | 88,87,90       |
|  | Test less than Control . . .   | 85             |
|  | No Plot effect . . . . .       | 89,86          |
| Incubation Phase/Nest . . .  | Test greater than Control. . . | 87             |
|  | Test less than Control . . .   | 85             |
|  | No Plot effect . . . . .       | 89,88,86,90    |
| Nestling Phase/Nest . . .  | Test greater than Control. . . | 88             |
|  | No Plot effect . . . . .       | 89,87,86,85,90 |

(this table continued on following page)

# SMALL MAMMALS AND NESTING BIRDS 1990 ANNUAL REPORT

Table 72. (Continued) Summary of major findings by task for 1985-1990.

| Task   | Results                        | Year                     |
|--|--------------------------------|--------------------------|
| <u>TREE SWALLOW - FECUNDITY, GROWTH AND MATURATION STUDIES</u>             |                                |                          |
| Tree Swallow Growth  |                                |                          |
| Weight increase <sup>b</sup> . . . . .                                     | Nest effect, No Plot effect. . | all years                |
| Weight inflection pt. . . . .  | Nest effect, No Plot effect. . | 90,88,87,86              |
|  | Nest and Plot effect . . . . . | 89,85                    |
| Maximum weight. . . . .  | Nest effect, No Plot effect. . | all years                |
| Age at maximum wt . . . . .  | Nest effect, No Plot effect. . | 90,88,87,86              |
|  | Nest and Plot effect . . . . . | 89,85                    |
| Tarsus growth <sup>b</sup> . . . . .                                       | Nest effect, no Plot effect .  | 90,88,87,86,85           |
|  | No Nest or Plot effect . . . . | 88                       |
|  | Nest effect and Plot effect. . | 89                       |
| Tarsus inflection pt. . . . .  | Nest effect, No Plot effect. . | 90,88,87,86,85           |
|  | Nest effect and Plot effect. . | 89                       |
| Maximum tarsus. . . . .  | Nest effect, No Plot effect. . | all years                |
| Age at maximum tarsus . . . . .  | Nest effect, No Plot effect. . | 90,89,88,87,85           |
|  | Nest effect and Plot effect. . | 86                       |
| Ulna growth <sup>b</sup> . . . . .   | Nest effect, No Plot effect. . | all years                |
| Ulna inflection pt. . . . .  | Nest effect, No Plot effect. . | 90,88,87,86,85           |
| Maximum Ulna. . . . .  | Nest effect, No Plot effect. . | 90,89,88,87,85           |
|  | Nest effect and Plot effect. . | 86                       |
| Age at Maximum ulna . . . . .  | Nest effect, No Plot effect. . | 90,89,88,87,86           |
|  | Nest effect and Plot effect. . | 85                       |
| Wing growth . . . . .  | Nest effect, No Plot effect. . | all years                |
| Incubation <sup>a</sup> . . . . .  | Nest effect,                   |                          |
|  | No Plot effect, No Year effect |                          |
|  | Ambient Temperature effect . . | 88,87                    |
| <u>DEERMOUSE - PARENTAL CARE, FECUNDITY, GROWTH AND MATURATION STUDIES</u> |                                |                          |
| Deermouse Growth   |                                |                          |
| Growth rate . . . . .  | Mother effect, No Plot effect. | all years                |
| Eye opening . . . . .  | Mother effect, No Plot effect. | 89,87,86                 |
|  | Mother effect and Plot effect. | 90,88 <sup>a</sup>       |
| Incisor eruption. . . . .  | Mother effect, No Plot effect. | all years                |
| <u>TREE SWALLOW HOMING STUDIES</u> (Pooled data for 1986-1989)             |                                |                          |
| Likelihood to Return. . . . .  | Test greater than Control. . . | 90,87                    |
|  | Test equal Control . . . . .   | 89 <sup>c</sup> , 88, 86 |
| Mean Return Times . . . . .  | Test less than Control . . . . | all years                |
| <u>SMALL MAMMAL HOMING STUDIES</u>   |                                |                          |
| Likelihood to Return   |                                |                          |
| Chipmunk. . . . .  | No Plot effect . . . . .       | all years                |
| Deermouse . . . . .  | No Plot effect . . . . .       | 88,87                    |
|  | Test less than Control . . . . | 90,89                    |

(This table continued on the following page.)

## SMALL MAMMALS AND NESTING BIRDS 1990 ANNUAL REPORT

Table 72. (Continued) Summary of major findings by task for 1985-1990.

### DEVELOPMENTAL STUDIES

Abnormality Frequency . . .No Plot effect . . . . . all years  
Egg Volume. . . . . .Nest effect, no Plot effect. . 90,89

### MAXIMUM AEROBIC METABOLISM STUDIES

#### Peak Metabolic Rates

Deermouse . . . . . .No Plot or Year effect . . . . all years  
Chickadee . . . . . .Test less than Control . . . . 88,87,86  
No Plot effect . . . . . . 90,89

- 
- <sup>a</sup> Study element dropped in 1989 due to budget constraints. See text.  
<sup>b</sup> Includes fitted growth constant and linear growth rate statistics.  
<sup>c</sup> Not tested in 1989 due to small sample N caused by inclement weather. Pooled over years including 1989, test plots have greater return rates than control.  
<sup>d</sup> Plot effect approaches significance (P=0.073).  
• Significant effects noted for plots are thought to be due to habitat edge, not antenna electromagnetic radiation.

SMALL MAMMALS AND NESTING BIRDS 1990 ANNUAL REPORT

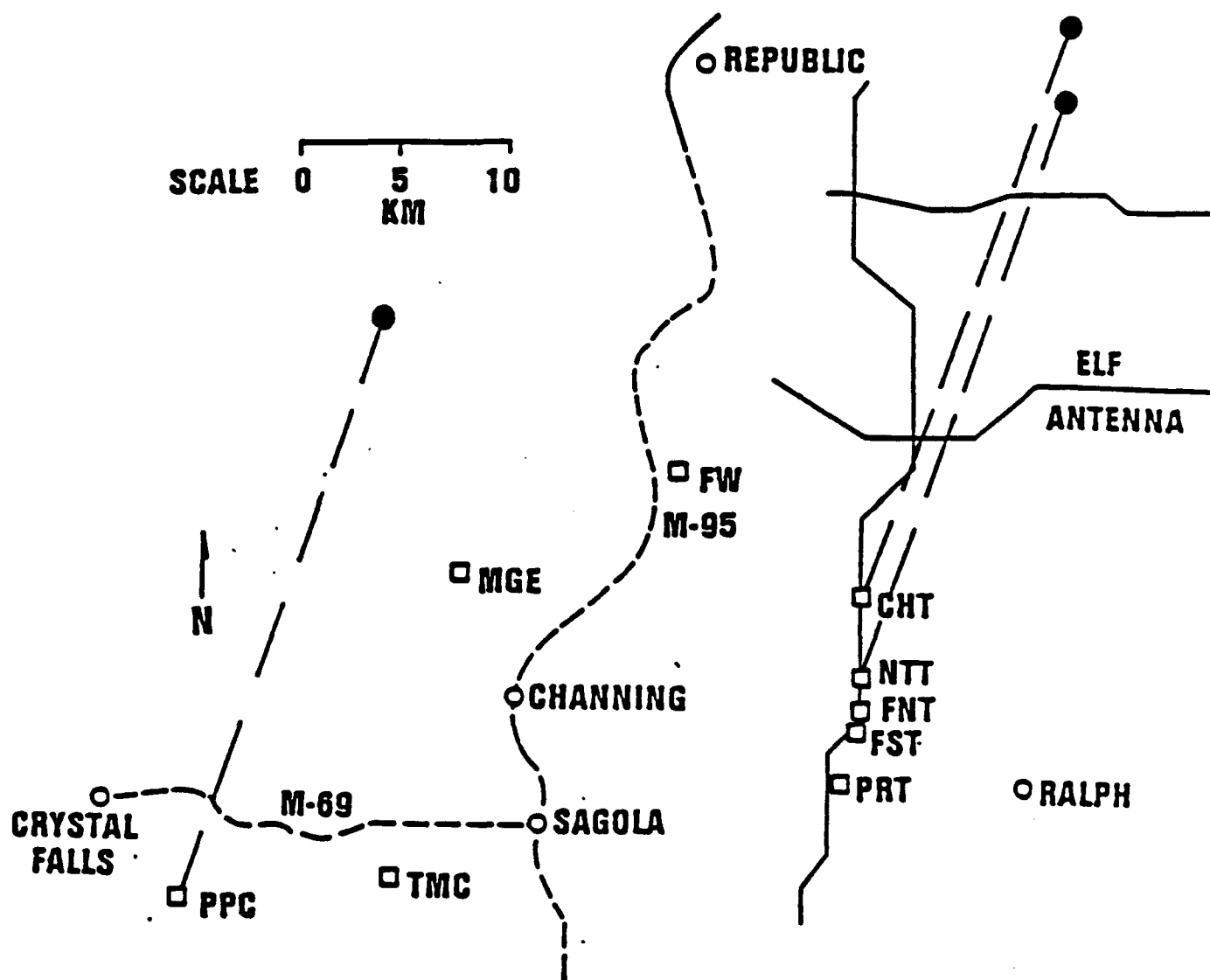


Figure 1. Location of Test and Control plots in relation to antenna system. See Table 1 for translation of plot codes.